"Aspects of passive cooling and the potential savings in energy, money and atmospheric pollutants emissions in existing air conditioned mosques in Saudi Arabia"

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DECLARATION

This thesis has been composed by myself and is my original work

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TO MY PARENTS

ABSTRACT

In Saudi Arabia, air conditioning is excessively used in both existing traditional and contemporary buildings. This process is currently responsible for (i) consuming substantial amounts of energy produced on a national level (40% of the total electricity produced) and (ii) emitting 11.7% of the national greenhouse and ozone-depleting gas emissions level (227,846,173 tonnes of CO_2 equivalent). The process, therefore, contributes largely to both economic and environmental threats of both global warming risks and ozone destruction.

Normally, in Saudi Arabia as in other countries where cooling is a seasonal or year-round requirement, existing large air conditioned buildings with intermittent occupancy patterns are today conventionally installed with air conditioning units. These tend to consume substantial amounts of electricity incurring high cost and emitting huge amounts of atmospheric pollutants compared to other smaller buildings types under continuous occupancy patterns. In Saudi, mosques form a significant proportion of these air conditioned buildings and their symbolic and cultural importance gives them an even greater significance than their simple numbers.

This study investigates the potential savings in air conditioning energy and reductions in atmospheric pollutants in existing air conditioned mosques in Saudi Arabia. It aims to study in particular the adoption of (1) proposed passive cooling strategy and (2) proposed passive cooling improvement measures for existing mosques. Existing air conditioned mosques in the city of Jeddah form the primary subject of this study. The proposed passive cooling strategy has been identified by a careful analysis of the climatic data, thermal comfort in mosque and mosque's occupancy pattern. The strategy is primarily related to the use of air movement and thermal mass for substantial number of prayers all year-round. As for the proposed passive cooling improvement measures, by surveying 48 existing air conditioned mosques, three passive cooling systems have been identified for improvements; the insulation values of the mosques' envelope, shading and night ventilation. Based on a better understanding of these passive cooling systems, combined with an analysis of the current economical, structural and constructional situations within existing air conditioned mosques, a coherent set of improvement measures has been established namely; (1) increased insulation values of mosques' fabric by adding various building and insulation materials for walls and roof, (2) increased shading by complete shading of windows and (3) increased night ventilation by ventilating the mosque for the whole night.

Passive cooling evaluation methods, appropriate to the strategy and the measures defined, have been adapted to predict the potential savings in air conditioning energy, money and atmospheric pollutants. These manual methods have been used to predict the various savings that can be achieved by applying the strategy and the measures of improvements to nine case study mosques. A set of comprehensive tables showing the potential savings in air conditioning energy, money and atmospheric pollutants emissions when applying these proposed measures for improving passive cooling systems in existing air conditioned mosques are produced. These tables can be used by architects, by the mosques' management and by the Ministry of Awkaf (Endowment) who are responsible for mosque procurement and maintenance. Finally, the study has estimated the potential savings of these proposed strategy and measures when applied to all existing air conditioned mosques in Jeddah and showing their relative contributions to reducing the national energy consumption and atmospheric pollutants emissions levels.

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CHAPTER ONE: INTRODUCTION

1.1 Sustainable development, emissions of noxious gases, existing air conditioned buildings and passive cooling

In this opening chapter, the foundation for the research is established in the form of a comprehensive account of the role of existing air conditioned buildings within the context of sustainable development in Saudi Arabia. The principal concerns of this chapter are (i) sustainable development, emissions of noxious gases and the environmental threats (ii) the discussion of major problems associated with existing air conditioned buildings which could have significant impacts on the environment and sustainability and the role of passive cooling to reduce this impact (iii) the definition of the passive cooling strategy in existing air conditioned buildings within the Saudi national environmental policy and (iv) a statement of the intention of this study, its main aims, objectives and methodology.

Currently, building research needs to be reviewed from a broad perspective that embraces each of economic, social and environmental issues. Therefore, the author has identified the concept of sustainable development as a major context for this research. The concept not only addresses the two critical issues of economy and environment in relation to buildings, but also reviews this relation from a global perspective.

In order to understand the relationship between buildings and sustainable development, it is essential to define the concept and its major constituents. The discussion of this concept is based on the authoritative work done by the World Commission on Environment and Development and other sources.

1.1.1 Sustainable development, emissions of noxious gases and the environmental threats

1.1.1.1 The concept of sustainable development

Sustainable development is defined by the United Nations Commission on Environment and Development as "development that meets the needs of the present without compromising the ability of future generations to meet their needs"[1]. The concept does involve handing on an inheritance that contains a balance of assets, both man-made and natural. Furthermore, "the concept does imply limits- not absolute limits but limitations imposed by the present state of technology and social organisation on environmental resources and by the ability of the biosphere to absorb the effects of human activities"[2].

The concept recognises two important factors. First, availability of natural resources; sustainable development requires that essential natural resources should not be extracted and destroyed at the rate they are today. It is important to put the emphasis on recycling and economising on the use of these natural resources to ensure that the resource does not run out before acceptable substitutes are available. Secondly, minimum impacts on the natural systems that support life on earth; sustainable development requires that the adverse impacts on natural systems like atmosphere, water and the soils should be minimised.

Activities such as emissions of noxious gases and heat into the atmosphere, the diversion of water courses, settled agriculture, genetic manipulation and commercial forestry carried out during the course of development are found to threaten these life support systems both locally and globally.

These noxious gases are carbon dioxide, sulphur and nitrogen dioxides and CFCs. Currently these gases are involved in the environmental crisis of global warming, ozone depletion and acid rain, putting the possibility of future development at risk.

1.1.1.2 Carbon dioxide, sulphur dioxide, nitrogen dioxide and chloroflurocarbons, and environmental threats

The contribution of carbon dioxide, sulphur and nitrogen dioxides and CFCs to the environmental crisis vary both quantitatively and qualitatively. Carbon dioxide is involved in the global warming or enhanced greenhouse effect, sulphur dioxides and nitrogen dioxides in acid rain and the CFCs gases are contributing to both the depletion of ozone layer and to the enhanced greenhouse effect.

The nature and scale of these contributions will be reviewed in depth through a discussion of each individual threat. The discussion will focus mainly on two main issues; the phenomenon and the possible consequences.

1.1.1.2.1 CFCs and ozone layer depletion

The earth's ozone layer has a very important role for living organisms in the planet. It absorbs the harmful ultraviolet (UV) radiation which affect plants and human beings and damages aquatic organisms. The layer is part of the atmosphere characterised by high concentrations of ozone gas, a form of oxygen where a molecule is composed of three atoms instead of the normal two. The layer occurs between 10 and 15 kilometres above the earth surface.

Convincing evidence is now available on the role of chloroflurocarbons (CFCs) and related compounds in depleting the concentration of ozone in the protective layer[3]. The scale and the power of depletion is very significant. CFCs tend to breakdown at altitudes of between 15 to 50 kilometres, releasing chlorine atoms forming chlorine monoxide (ClO). Each molecule of ClO has the potential for destroying 100,000 molecules of ozone[4], and consequently depleting the ozone layer and diminishing the potential of protection from ultra violet radiation.

No longer is the threat just to our future; the threat is here and now. In the Middle East, as predicted by the Cambridge scientist Joe Farman[5], a hole in the ozone layer occurs over Cairo reported by the National Research Centre where the ozone concentration was 130 ppm (parts per million)[6] over the central part of Cairo and Dukki showing an increase of 90 ppm above the normal level. Furthermore, NASA has forecast that ozone destruction is expected to take place north of 50° latitude[7].

Emissions of CFCs from many sources such as refrigerants are normally small but they are significant contributors to ozone depletion.

As far as the physical effects or the ecological consequences of changes to the ozone layer is concerned, little is yet known for certain. Nonetheless, awareness is growing of the types of damage both directly such as to human health, aquatic ecosystems and terrestrial plants, and indirectly via possible disturbance to the climate[8].

1. Human Health:

For human health, the depletion of ozone layer will increase rates of skin cancer, suppress the body's immune responses and cause damage to the eyes, especially in the development of cataracts. These effects would touch all populations, with some further consequences of possible increase in infectious diseases, severely affecting those in tropical and subtropical areas in particular.

2. Aquatic Ecosystems:

The impact of ozone layer depletion on aquatic ecosystems is becoming apparent. There is evidence that ambient solar UV-B radiation is acting as an important limiting factor in marine ecosystems. Suggestions have been made that roughly all marine fishes, all near shore flora and fauna, and many of the living things in estuaries and lagoons could be at risk. The enhanced UV-B levels have been shown to damage a range of small aquatic organisms (zooplankton, shrimp and larval crabs, and juvenile fish) and slowing photosynthesis in phytoplankton with a consequent risk of collapse of the rich ecosystems.

3. Terrestrial Plants:

As far as impacts on terrestrial plants are concerned, little is yet known about plants' response to enhanced UV-B. Limited studies on agricultural crops typical of mid-latitudes have been carried out to date. 200 species of plants have been shown to be sensitive to UV-B experiencing reduction in growth, inefficiency of photosynthesis process comparative to other plants and smaller amount of yields. This could, however, lead to changes in plant growth and therefore upset the delicate balance in natural ecosystems, potentially changing the distribution and the abundance of plants.

4. Climate:

The impact of ozone layer depletion on climate is not yet fully understood, but possible disturbance to the climate is confidently predicted. There are likely to be (i) changes to the temperature structure of the atmosphere through the temperature reduction or the coolness of the stratosphere region which is normally warmed by the absorption of the solar radiation in the presence of ozone and (ii) increases in the contribution of ozone to the enhanced greenhouse effect through the redistribution of ozone gas into the atmosphere as a result of its absorbing potential property to the infra-red radiation.

With these types of damages to human health, aquatic ecosystems, terrestrial plants and possible disturbance to the climate caused by the depletion of ozone layer via CFC gases, future development is at risk.

1.1.1.2.2 Carbon dioxide, CFCs and global warming

The earth's temperature rests on a delicate heat balance. Solar radiation passes into the earth through a mass of gases found in the atmosphere and is reflected back at different wavelengths through the same gases. These gases are nitrogen (78-85%); oxygen (20.95%); argon (0.93%) and the remaining trace gases known as greenhouse gases (0.035%)[9]. A complex system of ocean and air current, surface and cloud reflection, evaporation and precipitation, and absorption from the involved feed back system tends to keep the global energy balance nearly constant. While our climate is the result of a gigantic and complicated system that human activities cannot control or direct, the fragility of the heat balance renders it possible for human activities affecting greenhouse gases to alter critical leverage points in the climatic system.

Greenhouse gases are trace gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxides (NO_x), chloroflurocarbons (CFCs), and tropospheric ozone (O_3) which allow solar radiation into the earth but prevent heat radiated by the earth from being reflected back. There is overwhelming consensus that intervention in the form of increased atmospheric concentration of these greenhouse gases might affect the heat balance and lead to global warming[10]. The two gases of carbon dioxide and CFCs will be reviewed, due to their significant contributions.

1. The role of carbon dioxide

Two international groups of scientists under the auspices of the United Nations have been studying the problem of global warming and have come to similar conclusions. The planet faces a real danger of irreversible harm from increased carbon dioxide emissions. Their conclusions are borne out by a formidable body of scientific studies that implicate greenhouse gases in global warming[11] or enhanced greenhouse effect.

Carbon dioxide contribution to global warming is estimated at some 55% while the contribution of CO_2 in connection with the fossil fuels combustion is estimated to be at 35-40%[12]. The contribution of CO_2 emitted in the process of fossil fuels combustion related to electricity is estimated to be 11%[13].

2. The role of CFCs

Emissions of CFCs are normally small but they are significant contributors to global warming. Lashof and Ahuja have estimated their contribution at about 25% during 1980s[14].

The aim of the following section will be to look at just a few of the possible consequences of global warming on terrestrial ecosystems, agriculture and forestry, hydrology and water resources, ocean and coastal zones and human settlements and society. Some of these impacts in the Middle East region will be highlighted.

1. Impacts on natural terrestrial ecosystems:

A shift of several hundred kilometres of the climatic zones towards the poles is expected and therefore affecting both flora and fauna. In particular the northern forests will be severely affected. Under the condition of high speed climatic change, the responding ability for some species to adapt to the new condition might be too slow. Therefore, loss of biological diversity seems inevitable. With the disappearance of species as a result of over-hunting, over-collection and pollution the world may not only be losing valuable sources of food, medicine and industrial materials but also an invaluable genetic resource needed for future generations[15]. For those ecological habitats that have least opportunity to adapt, their species tend to be in greater jeopardy.

2. Impacts on Agriculture and Forestry:

Desert areas of Africa will advance. Water available will decrease, affecting areas like the African Sahel and the Mediterranean countries. The pattern of agricultural trade will be changed due to the decrease in the cereal production in Western Europe, southern and middle USA, Canada and Western Australia. In summer

1988, unusual heat and drought in North America and elsewhere, reduced the North American grain crop about 30% and therefore affected the price of grain globally[16]. Forest areas will mature and decline within a climate to which they will not be able to adapt. Therefore, the losses of wildlife is expected to be significant.

3. Impacts on Hydrology and Water Resources:

Many areas will be characterised by soil moisture, precipitation and water storage. Excess of supply will be a problem; it is predicted that serious flooding could occur in many northern rivers in former USSR[17]. In other areas, the availability of water will decrease, mainly due to the lack of rain affecting all the activities that are dependent on flows of fresh water from the land. For instance, lack of rain has cut water levels in rivers like Loire and the Rhone in Europe to half the normal height and to one third of the river Tigris in Iraq. In Algeria, water reserves have dropped by two thirds in the capital city in the past two years[18].

4. Impacts on Ocean and Coastal Zones:

Warmer average temperatures could also cause sea levels to rise, ranging between 25 and 140 cm, possibly as early as 2030[19]. A rise in the upper range would lead to the invading sea submerging whole cities, agricultural land, and fragile ecological coast land as well as swamping dump sites and salinating fresh water aquifers[20]. Areas at risk are Egypt, Maldives, Holland and East Anglia. A global rise of

2°C by the year 2100 could raise sea level to a point where Bangladesh loses about 35% of its most productive agricultural lands.

5. Impacts on Human Settlements and Society:

At prospect is the displacement of hundreds of millions of people world wide next century, not only due to the inundation of low lying coastal plains, deltas and islands but also due to the biotic impoverishment and aridity spread. The implication of global warming for human health involve the spread of diseases commonly not found in certain regions. These diseases are malaria, schistomiasis, Japanese encephalitis, dengue and leishmaniasis which are expected to shift north as the world warms[21].

1.1.1.2.3 NO_X, SO_X and acid rain

Acid rain is a term which describes a mixture of air pollutants which react with water, mist rain or snow to form acidic solutions which can have severe adverse effects on the lower parts of the food chain, tree growth, mosses, fresh water fish stocks and future impacts upon metal structures and buildings. These air pollutants are products of fossil fuels combustion such as sulphur and nitrogen dioxides in addition to sulphate, nitrates and ammonium compounds and sulphuric and nitric acid[22].

The damage caused by acid rain is felt not only in the neighbourhood of the source in a form of dry deposition, but also at distances of hundreds or even thousands of kilometres, as a result of long-range transport in a form of secondary pollutants (transformed by sunlight). Once these secondary pollutants return to the earth in a form of wet deposition (rain, snow, mist) they potentially can increase the natural acidity of soils and the groundwater. Acid rain is a problem recognised to have regional and global significance.

Acid deposition has been observed in many parts of the world[23] and particularly in central Europe, Scandinavia, over large sections of eastern Canada and parts of the western US and the north-eastern US. Some 50% of former West German forest is thought to be affected. Moreover, 1.2 million acres of land in former Czechoslovakia are dead. In the UK, high levels of acid damage have also been recorded[24]. Brown[25] reported that Britain is suffering from unexpectedly high levels of acid rain.

1.1.2 Existing air conditioned buildings, emissions of noxious gases and passive cooling to reduce the environmental impacts:

The building sector contributes to these environmental threats of global warming, acid rain and ozone depletion[26] threatening the possibility of future development.

The role of buildings in the environmental crisis can be realised through their part in emitting environmentally damaging gases. Buildings are responsible for emitting significant proportions of gases polluting the atmosphere beyond the local region. The primary gases are carbon dioxide, sulphur dioxide, nitrogen dioxide and chlorofluorocarbons (CFCs). The sources of these gases as related to the building sector are due to the energy involved in the provision and use of this sector (embodied and operational energy with the major contribution of the latter as discussed in the previous section) and to the chemicals present in materials used in building services and components[27].

The emissions of these gases are brought about through two different processes. The first process is by the combustion of fossil fuels in order to generate the energy used for the building sector[28]. The second process is mainly through operational leakage, through plant failure and during maintenance of refrigerants in air conditioners in addition to releases from insulation materials[29]. The general pattern of building contribution to the environmental crisis with the concerned gases is outlined in fig. 1.1.

The following discussion will define these emissions as related to (a) building in general and (b) existing air conditioned buildings in particular. The discussion will be carried out under two main headings; (i) existing air conditioned buildings and the emissions of carbon dioxide, sulphur dioxide and nitrogen dioxide (ii) existing air conditioned buildings and the emissions of CFCs.

1.1.2.1 Existing air conditioned buildings and the emissions of carbon dioxide, nitrogen oxide and sulphur dioxide

The combustion or burning of fossil fuels to generate energy necessary for the building sector leads to the production of noxious gases including carbon dioxide[30],

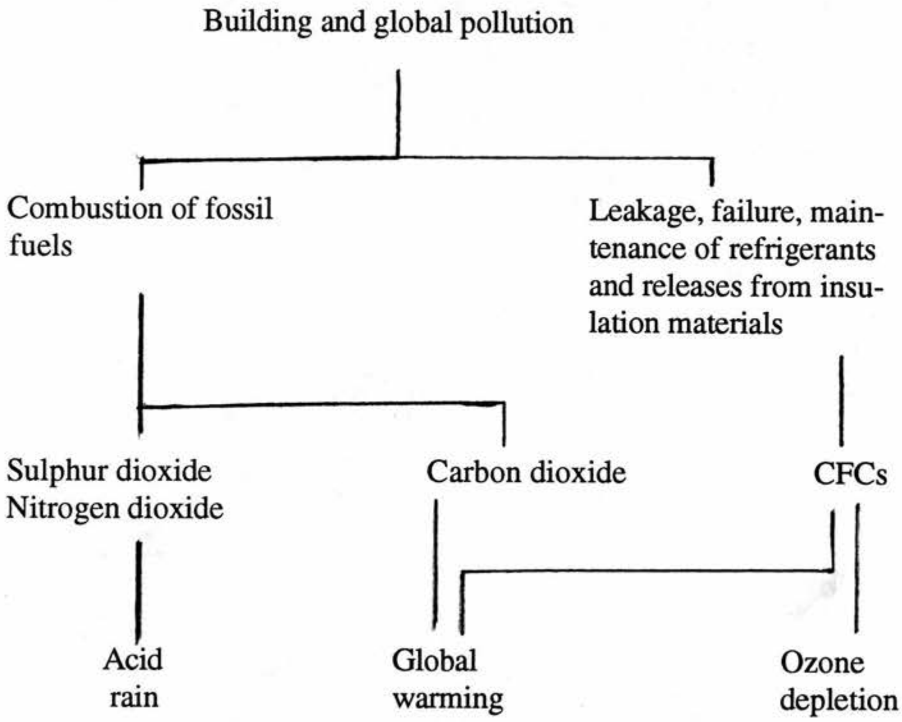

Figure 1.1 Summary of building contribution to global environmental threats.

sulphur dioxide, nitrogen oxide[31], and nitrous oxide[32]. In addition methane gas is also emitted as a result of fossil fuels processing such as oil and gas exploitation, leaks and coal mining[33]. The present discussion will be confined to emissions of toxic gases associated with electricity generation. The amount of certain emitted gases from electricity tends to be significant. For instance, carbon dioxide emissions per unit of energy delivered by electricity is much more[34,35] when compared with other fossil fuels used in building (see Table 1.1).

Environmental impacts associated with electricity generation from fossil fuels are of two categories; direct and indirect. The pollution of air and water and the use of natural resources are direct impacts, while others such as aesthetic considerations, social and habitat modifications, are indirect. Table 1.2 lists the major environmental problems accompanying electricity generation. As far as the direct impact on air is concerned, air pollutants from these power plants are diverse. Nitrogen and sulphur oxides, carbon dioxide, particulate and trace elements are considered to be the major air pollutants through carbon monoxide, fluorides, hydrocarbons and chlorides are released in relatively minor quantities. Small amounts of radioactive materials such as uranium and radon are also discharged[36].

The emission rates of sulphur dioxide, nitrogen oxide and carbon dioxide from fossil power plants differ with the type of fuels used. Table 1.3 gives estimates for these emission rates, relevant to coal, oil and natural gas[37].

The emissions of CO_2 as related to electricity production and to building use,

Table 1.1 Carbon dioxide emissions per unit energy delivered (Kilogram per giga joules) as related to different fuels

Electricity	231 Kg/Gj
Coal	92 Kg/Gj
Oil	84 Kg/Gj
Natural gas	55 Kg/Gj

Source: R. Talbot, "Building, Energy and the Greenhouse Effect". *RIAS Practice Information*, March 1990, p. 29.

Table 1.2 Environmental problems associated with electricity generation from fossil fuels.

Land and water use
Air emissions (SO_x, NO_x, CO_2, CO, HC, Trace elements, Particulate, Radionuclides
Long range transport and deposition of air pollutants
Thermal releases
Local climate and visual impacts from the use of cooling towers
Solid waste disposal (sources with particulate and/or SO_x control)
Ash disposal (from coal)
Noise

Source: Organisation for Economic Co-operation and Development, Environmental Effects of Electricity Generation. OECD, Paris 1985, p. 13 and 66.

Table 1.3 Emission rates from fossil fuel plants

Fuel	SO_x	NO_x	CO_2
Coal:			
3.0 % Sulphur	205	32	8013
1.2 % Sulphur	7.7	3.5	-
0.6 % Sulphur	54	44	8393
Oil :			
2.0 % Sulphur	84	28	6577
Natural gas	.02	25	4461

Source: United States Department of Energy, Energy Technologies and the Environment: Environment Information Handbook, 1981.

represents a relatively high fraction of the total CO_2 emissions on a national level in some countries. For instance, in Saudi Arabia[38] in 1988, the electricity sector alone emitted 23,038,799 tonnes mainly of CO_2 where 14,975,319 tonnes mainly of CO_2 emission is attributable to buildings (based on the fact that 65% of the total electricity produced in the country is used in buildings). In the USA[39], electric power generations contribute approximately 45% of the total carbon dioxide emissions at an estimated amount of 450 million metric tonnes of CO_2. Around 300 million metric tonnes is related to buildings (based on the fact that 75% of the total annual electricity sales is devoted to operating the equipment and appliances in buildings as discussed before). In the UK, energy demands for building are responsible for about half of the total CO_2 emissions. Almost half of the CO_2 emission attributable to buildings is related to electricity use. Electricity is mainly generated from coal[40].

As far as emissions of both sulphur and nitrogen oxides as related to electricity generation and to building are concerned, fossil fuel power plants are responsible for emitting substantial amounts of both noxious gases. For instance, the two power plants in the city of Jeddah emit 3498 tonnes of sulphur dioxide and 1410 tonnes of nitrogen oxide on monthly basis[41]. Due to the fact that 65% of the total electricity produced is consumed in buildings in Saudi Arabia[42], buildings in Jeddah are, therefore, responsible for discharging a monthly average of 2273 tonnes of sulphur dioxide and 916 tonnes of nitrogen oxide. In 1988 United Kingdom power plants were responsible of emitting 71% of the total sulphur dioxide (2,598,600 million tonnes and 32% of the NO_x (800,000 tonnes)[43].

Overall, the contribution of buildings to global atmospheric pollution is shown to be mainly through the emissions of nitrogen and sulphur oxides and carbon dioxide related directly to electricity generation.

The contribution of building to both environmental threats of global warming and acid rain are shown to be through the use of electricity, where major emissions of these gases occur during electricity generation. Therefore, the more electricity is needed for the building sector (particularly for operational energy) the more emissions of these toxic gases is produced.

There is no definitive figure for the contribution of sulphur dioxide and nitrogen oxide emissions attributable to building to the acid rain pollution but the estimated contribution is high, based on the fact that emissions of SO_2 and NO_x from power plants are much greater compared to the other sources, such as motor vehicles and large industrial plants. For instance, over 75% of Britain's emissions of sulphur dioxide comes from power stations[44].

Current emissions of CO_2, NO_x and SO_x from existing air conditioned buildings are very high. Emissions of CO_2 as related to existing air conditioning has reached high levels in some countries. For instance, it represents 40% of the total amount of CO_2 emission of/from the total electricity produced in Saudi Arabia[45] and 70% in Kuwait and Qatar[46,47]. The same scenario is applicable for the other two gases.

1.1.2.2 Existing air conditioned buildings and the emissions of chlorofluorocarbons

Being non-toxic, non-flammable, odourless and colourless gases, CFCs have widespread applications in industry. In the building sector, CFCs are used in insulation materials and as refrigerants in air conditioning systems. In addition, CFCs are used in a number of products that are commonly used in buildings such as refrigerators, freezers and in the foam of some furniture products[48]. The use of CFCs (R11, R12, etc) in buildings was unquestioned for almost half a century and growth of their use was rapid and sustained during that period[49].

Significant amounts of CFCs have been produced through the whole world. World production of CFCs was approaching some one million tonnes per year by 1988[50]. In 1988, Britain alone exported 48000 tonnes of CFCs of which 3759 tonnes were sold to the Middle East[51].

The amounts of CFCs used as refrigerants in air conditioners, refrigerators, freezers, etc and as blowing agents in the production of insulation materials differ from one country to another. In the UK, in 1989 it is estimated that 4370 tonnes of CFCs were used as refrigerants and 4200 tonnes of CFCs for building related insulation products[52]. In Saudi Arabia, the amount of CFCs used as refrigerants is twice the amount used for the production of insulation materials[53].

The use of CFCs, as refrigerants in air conditioning and as blowing agents for insulation materials, in the building sector has grown in some countries. For instance, in the UK, the consumption of CFCs grew from 7.5% in 1986 to 15% in 1989[54,55].

As far as the use of CFCs in air conditioning systems is concerned, the amounts of CFCs used for this purpose tend to be high. In Britain, about 31% of the total amounts of CFCs used as refrigerant (4370 tonnes) was used for air conditioning systems in 1989[56]. In Saudi Arabia, substantial amounts of CFCs were also used in air conditioners due to the fact that there are around 23 million air conditioners working in the country[57] using CFCs gases.

The emissions of CFCs gases from building can be recognised through the processes of operational leakage, plant failure and during maintenance of refrigerants in air conditioners, freezers, and refrigerators in addition to releases from insulation materials[58].

Emissions of CFCs gases from refrigeration and air conditioning seem to be large in some countries. For instance, in Saudi Arabia, emissions from these practices is accounted for probably more than two thirds of the total CFCs national emissions which was estimated to be 21.4 million tonnes in 1970 and 41.1 million tonnes, of carbon dioxide equivalent in 1990[59].

Overall, the building contribution to global environmental threat of ozone depletion is shown to be mainly through the emissions of CFCs from insulation materials and the refrigerants in air conditioning systems. There is as yet no total figure available for the contribution of the CFCs emissions attributable to building due to the difficulties in monitoring their emissions.

At present, however, emission of CFCs from existing air conditioned buildings is estimated to be high due to the great numbers of existing air conditioning systems in use all over the world. Millions of air conditioning systems (a/c) have been sold to those countries that are well off, have warm climates and can afford to buy, like the Middle East[60].

1.1.2.3 General strategies to reduce the emissions of CO_2, SO_2, NO_x, and CFCs as related to air conditioned buildings

Strategies are needed urgently towards existing air conditioned buildings. This is due to the following facts:

1. Existing air conditioned buildings are much greater in numbers than those new buildings added every year.

   Sir Allan Pullinger in his article "Low Energy Air Conditioning: A Challenge for the Industry" said; *"Perhaps the most important to note is that the policies adopted to improving existing buildings would make a much greater and more immediate impact on energy consumption that those for new buildings, since we only add one or two per cent to our new building stock each year"*[61].

2. More emissions are expected from air conditioned buildings:

   Mr John Butler of the BRE said *"Air conditioned buildings contribute a disproportionately high share of pollutants from buildings"*[62].

3. Air conditioned buildings contributes to the two environmental threats of

global warming and ozone depletion:

> Professor John Page said "*In contemporary air conditioned buildings, human cooling is achieved at the expense of adding to both global warming risks and to ozone destruction*"[63].

Strategies to reduce the emissions of CO_2, SO_2, NO_x and CFCs as related to existing air conditioned buildings are known to be as follows:

1. Introducing more efficient air conditioners[64].
2. Achieving very low rates of refrigerant loss if the system is well engineered and maintained[65].
3. Using aspects of passive cooling in existing buildings[66,67].

The first two strategies cannot be applied in the short term due to two main constraints:

1. High efficiency air conditioning systems are still under development[68]. Moreover, the replacement of existing air conditioning systems with more efficient ones is not economically worthwhile when the existing one is still in good condition[69].
2. Proper maintenance and engineering of a/c systems won't be available at a large scale in a short time particularly in the developing countries[70], e.g. the Middle East[71]. This is due to the following facts:
    1. Lack of technology.
    2. Lack of experts and poor quality labour.
    3. High cost.

Aspects of passive cooling must thus be seen as a priority response. This study will focus on the application of aspects of passive cooling and the reduction of environmental impacts from existing air conditioned buildings.

1.1.3 Aspects of passive cooling in existing air conditioned mosques within the Saudi environmental policy concerning emissions of noxious gases as related to existing air conditioned buildings

The author argues that passive cooling strategies in existing air conditioned buildings need to be addressed in every environmental policy for every country. The author, therefore, would like to address these strategies within the context of the Saudi Environmental policy.

1.1.3.1 The Saudi environmental policy as related to emission of noxious gases

1.1.3.1.1 General perspective on the Saudi environmental policy

During the last two decades, the Kingdom has undergone a unique process of development that has been comprehensive in its coverage of all aspects of Saudi society.

There has been development in all sectors of economy, education, health, energy, transportation, urbanisation and the utilisation of natural resources (e.g. land, water, etc.). Particular emphasis has been given to the environmental consideration developed and adopted by the government of the Custodian of the Two Holy Mosques during the last two decades in view of protection of the environment and conservation of resources as a pre-requisite for sustainable and balanced development. Such concern has been a strategic objective and priority expressed in the development plans of the Kingdom. This priority recognises the necessity of satisfying current needs without impairing the ability of future generations to utilise natural resources in meeting their requirements.

The government of Saudi Arabia has established the basis for an environmental strategy in which planning, institutional, implementation and structural aspects are integrated to reflect the particularity of the national development process as well as the characteristics of Saudi society and its culture.

On the planning level, the Fifth Development Plan (1990-1995) has adopted an environmental strategy that applies to all sectors in the national development[72].

The application of this strategy at institutional level is achieved by:

1. The restructuring of the Meteorology and Environmental Protection Administration (MEPA) in 1981 for undertaking the role of a central agency nationally responsible for the protection of the environment.
2. The forming of the Ministerial Committee on the Environment to undertake planning, coordination and formulation of national environmental strategy and to suggest positions to be adopted by the Kingdom in the international arena.

3. The establishing of the National Commission for Wildlife Conservation and Development (NCWCD) in 1986.

On the implementation level, major industrial projects in the Kingdom have taken the environmental dimension into consideration in all phases of their design, construction and operation.

On the organisation and control level, environmental impact assessment has been adopted for development projects; the concerned agency is now in the process of preparing comprehensive regulations for environmental surveillance and assessment.

The Kingdom admits the fact that environmental issues cannot be dealt with within a narrow national context. It has contributed to all the international activities pertaining to environment and exhibited cooperation to the utmost extend possible. Among these are:

1. The participation in all meetings of the Preparatory Committee of the United Nations Conference on Environment and Development and in the Earth Summit at Rio.
2. The organisation of a national conference on environment and development in collaboration with the concerned United Nations agencies.
3. Active in regional environmental activities best example is its cooperation in combating the environmental impact of war for the liberation of Kuwait[73].

1.1.3.1.2 Estimation of noxious gases emissions

MEPA, with collaboration with the Saudi Arabian Oil Company (Saudi Aramco) and King Fahd University of Petroleum and Minerals (KFUPM), has estimated sources and emissions of greenhouse and ozone-depleting gases in the Kingdom[74]. MEPA estimates for 1988 are given in Table 1.4. Total greenhouse and ozone-depleting gas emissions for Saudi Arabia in 1988 was 227,846,173 tonnes of carbon dioxide equivalence. This consists of:

CO_2 = 152,656,930 tonnes (67%)

NH_4 = 41,012,311 tonnes (18%)

CFCs = 33,493,387 tonnes (14.7%)

NO_x = 683,545 tonnes (0.3%)

An estimate of CO_2 and CFCs emissions for three different years as related to air conditioning in Saudi Arabia is shown in Table 1.5. In 1988, the emission from air conditioning represents 11.7% of the total national emissions. This amount is considered to be high and an urgent strategy is needed.

1.1.3.1.3 Avenues of attack on the problem of greenhouse and ozone-depleting gas emissions and the need for comprehensive policy regarding the applications of aspects of passive cooling in existing air conditioned buildings

The Kingdom has considered five avenues of attack on the problem of greenhouse and ozone-depleting gas emissions[75]. These are summarised as follows:

Table 1.4 1988 Saudi Arabia greenhouse and ozone-depleting gas emissions

Sector	Tonnes CO_2 equivalency	% of total
Indust. & argicul. sources:		
Industrial electricity	07,435,343	3.2
Bunkers	19,347,460	8.4
Cement	09,822,725	4.3
Refinery	09,502,231	4.1
Natural gas production	03,706,350	1.6
Agriculture	08,146,617	3.5
Livestock	07,917,703	3.4
Other industrial	46,817,136	20.5
Total Industrial and agriculture emissions	112,695,565	49.5
Sources from human services and commercial activities:		
Landfill	14,775,600	6.48
Electricity	23,038,799	10.11
Sewage	647,521	0.28
Vehicles	30,656,650	13.45
Aviation	06,491,189	2.84
Desalination	03,177,691	1.39
LPG use	01,173,726	0.51
Miscellaneous	35,189,432	15.44
Total human services and commercial activities	115,150,608	50.5
Total emissions	227,846,173	

Source: MEPA, Ministry of Defence (1992). State of the Environment in the Kingdom of Saudi Arabia 1992. p. 5.

Table 1.5 Estimate of CO_2 and CFCs emissions as related to air conditioning (Tonnes)

Year	CFCs	CO_2	Total
1977	9,273,333	unknown	unknown
1988	14,513,801	12,189,657	26,703,458
1990	17,810,000	unknown	unknown

1. Increase in carbon sinks:

MEPA has proposed ways to increase the amount of terrestrial sinks as follows:

a. Afforestation of Wadi valleys and suitable high land areas.

b. Establishment of green belts around the towns and cities.

c. Increase of mangroves along the coasts.

2. Decrease in emissions:

Decrease of emissions to satisfactory levels. Decreases were significant in the reduction of Methane and nitrous oxides gases limited only to natural gas production. This has been achieved by the installation of master gas collection systems. Table 1.6 shows the magnitude of this reduction.

3. Research on emissions:

Intensifying research on possible global warming through three channels:

a. The operating of 29 manual meteorological stations and 22 synoptic automatic weather stations (AWS) so as to monitor air quality, cloud cover and precipitation by MEPA.

b. The construction of a global Background Air Pollution Monitoring Networks (BAPMoN) station in the southern region of Saudi Arabia. This station is the only one in the region and will measure concentrations of CO_2 and other atmospheric constituents contributing to the global warming.

c. MEPA has organised an internal working group on global warming which meets weekly to coordinate and assess both national and international

Table 1.6 Reductions of NO_x and NH_4 in tonnes.

Gas	1980	1984-1991
NO_x	21,1990	Insignificant emission
NH_4	38,787	Zero

information and arrange liaison with other relevant agencies.

4. Joining the international treaties for attacking greenhouse and ozone-depleting gas emissions:

   a. The Kingdom has secured a concession on the Climatic Change Treaty (Agenda 21) in Rio which calls for lowering carbon dioxide emissions which is believed to cause global warming. This decision is based on two issues. First, the Saudi believe that there is a scientific uncertainty of CO_2 being as a polluter or even as the principal polluter. Secondly, the Saudi national income will be affected strongly as the convention calls for a reduction in oil consumption[76].

   b. The Kingdom has recently joined the Vienna Convention for the protection of the ozone layer and the Montreal Protocol and the amendment involved on substances that deplete the ozone layer[77].

5. Energy planning:

   The Kingdom is adopting two main strategies

   1. Increase in energy efficiency.
   2. Developing alternative energy sources.

Firstly, the increase in energy efficiency covers the following topics:

a. The single greatest increase efficiency in electricity production through the introduction of Dual Purpose Salination plants.

b. Increase efficiency in the area of transportation through:

1. increasing fuel efficiency in vehicles.

2. improving city traffic light systems.

3. improving energy/environment awareness on the part of drivers.

4. increasing efficiency of mass transportation systems.

c. Increase efficiency in the use of electricity in buildings through:

1. on long term basis, improvement of building regulations and standards.

2. introduction in 1985 of a block tariff for non-residential sector.

3. implementation of a national information campaign aimed at energy conservation and rational use of electricity in buildings.

4. compulsory installation of insulation in government and commercial multi-story buildings.

5. for ordinary buildings, building permission is appended with a leaflet containing information on the benefits of insulation but these they are not compulsory.

Secondly, the kingdom encourages the efforts to find out other alternative energy sources. This has been the work of another government agency named King Abdulaziz City for Science and Technology. The agency is conducting explorative research in the use of solar energy. Current programmes are:

a. Photovoltaic powered devices, e.g. for traffic signals.

b. Solar energy cooling at King Abdulaziz, King Saudi and King Fahd Universities.

c. Solar project for date ripening and drying.

d. Photovoltaic research on PV collector and establishment of a thermal collector at the solar village near Al-Uyayna.

e. Solar hydrogen production.

General comments from the author's view on the Saudi environmental policy are summarised as follows:

1. Good effort from a developing country towards the current environmental problems.
2. Covers the major sources related to air pollution.
3. Good strategy related to future multi-storey buildings concerning the use of insulation.
4. Strategy on the reduction of CFCs are general.

However, the main gaps in the policy as far as building is concerned are as follows:

1. Strategy on existing air conditioned buildings is totally ignored.
2. Strategies related to buildings are only limited to one building type (commercial multi-storey) and to the use of insulation.
3. Strategy connected with existing CFCs used in buildings is not considered.

1.1.3.2 Aspects of passive cooling in existing air conditioned buildings

From the discussion above, it can be seen clearly that at the present there is a significant gap in the Saudi Environmental Policy regarding existing air conditioned buildings. A comprehensive policy on the application of some aspects of passive cooling systems in existing air conditioned buildings is therefore urgently needed. It is the intention of this research to fill this gap by studying the application of some important aspects of passive cooling in existing air conditioned buildings and calculating their potential savings in air conditioning energy, money and CO_2 and CFCs emissions levels.

These existing air-conditioned buildings are of different types and functions:

1. Residential buildings such as apartments and villas.
2. Commercial buildings such as offices and shops.
3. Educational buildings such as schools.
4. Health buildings such as hospitals and health centres.
5. Religious buildings such as mosques.

In order to develop a comprehensive environmental policy related to the applications of these aspects in existing air conditioned buildings, all building types listed above need to be studied. Unfortunately with the limited effort, time and money, this study will be constrained to religious buildings and the mosque in specific.

1.2 Aspects of passive cooling in existing air conditioned mosques

There are several reasons regarding the selection of mosques in this study:

1. The increase on the current action of air conditioning existing and new mosques that has electricity with no building regulation available.

2. Arising claims from mosques' management concerning the substantial amount of money currently paid for the electricity bills.
3. The mosque is a major source for correcting lots of our personal behaviours and the idea of applying the environmental conservation in it will encourage others to follow.
4. Lack of research on the application of environmental control systems in mosques.
5. As a personal interest, for the last ten years the author has involved himself in studying, designing and supervising some mosque projects in Jeddah.

Jeddah's Mosques have been nominated in this study for the following reasons:

1. Huge diversity of existing air-conditioned mosque as far as age, design and form are concerned.
2. Jeddah was among the first cities in the Kingdom where air conditioning of mosque was introduced.
3. Jeddah is among the larger cities in the Kingdom; has more than 1000 mosques.
4. The author knows the city very well and has been in touch with its development for the last 30 years.

1.3 The aims and objectives of the study

The study investigate the use of passive cooling aspects in existing air conditioned mosques and their potential savings in air conditioning energy, CO_2

emissions, and CFCs emissions by adopting (1) proposed passive cooling strategy and (2) proposed passive cooling improvement measures. The aims of the study are as follows:

1. To define the passive and active cooling strategies in mosque.
2. To define the necessary improvement measures applicable to existing passive cooling systems.
3. To develop calculation methods able to predict the potential savings in air conditioning energy, CO_2 emissions, and CFCs emissions as well as money and cost effectiveness with regard to the proposed passive cooling strategy and the measures defined.
4. To investigate the applications of the proposed strategy and the improvement measures in existing air conditioned mosque and calculating their different potential savings.

1.4 Methodology and structure of the study

The thesis consists of three main parts, each of which develops from the findings of the previous section. These parts are structured in nine chapters and can be briefly summarised as follows.

The first part is mainly concerned with the theoretical basis of the research. The section is divided into two chapters.

Chapter One as introduction, has defined the role of existing air conditioned buildings in general and mosques in particular within the context of sustainable development and the urgent need of applying some aspects of passive cooling.

Chapter Two discusses the air conditioned mosques of Jeddah, its management, physical characteristics, and the various appliances used.

The second part of the study is concerned with the determination of passive cooling strategy and the passive cooling improvement measures for existing mosques. This part of the study is divided into four chapters.

Chapter Three investigates the establishment of the passive cooling strategy in mosques produced for the first time by analysing the climatic data for 13 years, the comfort level needed in mosques and the prayer times.

Chapter Four, Five and Six are related to the determination of the passive cooling improvement measures. Chapter Four reviews and evaluates the passive cooling systems; the passive cooling systems used in Jeddahs' mosques and mosques in other locations similar to Jeddahs' climate and their applicability for cooling the mosques.

Chapter Five analyses and evaluates the survey results, to study the different passive cooling systems which have significant contribution to the current amounts of air conditioning energy and CO_2 and CFCs emissions levels. The survey is conducted on 48 existing air conditioned mosques spread in particular sections of the city. The method by which the survey is conducted is by obtaining the necessary information by means of observation, interviews and from archives of detailed drawings. The survey analysis specifies that the passive cooling systems as related to insulation values of mosques' envelope, shading and night ventilation have the most significant contributions to the current amounts of air conditioning energy and CO_2 emissions indicating the urgent need of applying improvements to these systems.

Chapter Six is devoted to understanding and analysing the principles, strategies and means of these systems and therefore help in defining the various measures of improvements. Three passive cooling improvement measures has been suggested; increased insulation values of mosques' envelope by adding a composition of building and insulation materials for walls and roofs, increased shading by complete shading of windows, and increased night ventilation rates by ventilating the mosque for the whole night, i.e. 7 hours.

The third part of the study comprises (1) the potential saving calculation methods; able to predict savings in air conditioning energy, CO_2 emissions and CFCs emissions as related to the proposed strategy and the measures of improvements and (2) the applications of the passive cooling strategy and the passive cooling improvement measures in nine mosque categories and the estimated potential savings achieved.

Chapter Seven discusses the development of the potential savings calculation methods of the strategy and the improvement measures. The savings calculation method related to the strategy is simple and straightforward. The savings calculation method of the improvement measures involves the modifications of the Passive Cooling Evaluation Method (PACE); originally designed to predict the potential saving in air conditioning energy, as related to increasing U-values of building envelopes, shading and night ventilation. The two methods have been modified to predict savings in money and CO_2 and CFCs emissions and the cost effectiveness of the proposed strategy and measures within the context of an intermittent occupancy pattern of mosques.

Chapter Eight is composed of two sections. The first one is studying the applications of the proposed strategy and the improvement measures defined (Chapters Three and Six) in nine case study mosques estimating their potential savings that can be achieved with the use of the calculation methods discussed in Chapter Seven. The second part discusses (1) the strategy and the improvement measures performances in each mosque category, (2) the development of potential saving tables easy to predict the amount of savings in air conditioning energy, money, CO_2 and CFCs emissions that can be achieved when applying any of the proposed measures to any air conditioned mosque and (3) the potential savings of the proposed passive cooling strategy and the proposed passive cooling measures at the city level as well as their contributions to the total national air conditioning energy consumption as well as CO_2 and CFCs emissions.

Chapter Nine provides a comprehensive conclusion for the whole thesis, summarising the findings of the different chapters of the thesis, and setting out the overall recommendations derived from the analysis of the thesis. Finally the thesis is concluded with selected subjects recommended for future research.

In this chapter, the foundation for the research has been established in the form of a comprehensive account of the role of existing air conditioned buildings within the context of sustainable development. The principal concerns of this chapter are (i) sustainable development, emissions of noxious gases, and the environmental crisis, (ii) the discussion of major problems associated with existing air conditioned buildings which could have significant impacts on the environment and sustainability and the importance of passive cooling to reduce this impact and (iii) the aspects of passive cooling systems in existing air conditioned buildings within the Saudi national environmental policy (iv) the focus of this study, its main aims, objectives, and methodology and structure of the study.

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CHAPTER TWO: EXISTING AIR CONDITIONED MOSQUES IN JEDDAH

The main objective of this chapter is to give general information about Jeddah's existing air conditioned mosques. The discussion covers mainly four topics. These are:

1. The construction, operation and installation.
2. The physical characteristics.
3. The typical electric appliances used.
4. Estimation of CO_2 and CFCs emissions from these appliances.

2.0 Mosques, non-air-conditioned mosques and air conditioned mosques

The mosque can be defined as a place where Muslims perform their prayers. The English word "mosque" seems to be derived from the French "*mosquee*", which in turn derives from the Spanish "*mezquita*", from the Arabic "*masjid*"[1] a place of prostration.

The Muslim believes in the omnipresence of Allah (God), and consequently can perform his prayers anywhere and in any place, be it covered or open to the sky, provided that it is clean i.e. not a dirty place.

However, there are two reasons behind the act of praying in mosques. Firstly, a prayer offered in a group or a congregation is far more meritorious than a single or a private prayer performed elsewhere. This can be supported by Hadiths (sayings and traditions of the prophet) among which is the saying:

> ***"only seven shall enjoy the shade of God on a day without any shade ... one of these is a man whose heart is completely attached to mosques"***[2].

Secondly, the mosque is also a meeting place where Muslims can discuss religious and moral matters and teach or learn social and religious studies. These practices take place not only in old mosques, such as Al Azhar Mosque at the University in Cairo or Zeytuna Mosque in Tunis, but also in every recent mosque. It is even used by some people as a place merely for rest and meditation.

The Arabic word "*Jami*", which means "place of assembly for the congregation" is also used for a mosque where Friday prayers are performed and sometimes also for a large scale mosque.

In terms of their electricity consumption, mosques can be classified into two groups; (1) low consumption mosques where electricity usage is largely confined to light, sound amplifiers and fans (2) high consumption mosques where electricity usage extends also to refrigeration and air conditioning. It is the intention of this study to focus on the latter group. This group will be called "air conditioned mosques" in this research. Moreover, the discussion in this chapter will be mainly devoted to Jeddah's existing air conditioned mosques. These mosques are either modern or very old ones equipped with these five types of appliances only recently.

There are over 30000 mosques in Saudi Arabia. Table 2.1 summarises the number of mosques in major regions in Saudi Arabia[3,4]. More than 50% of these mosques are air conditioned.

The number of air conditioned mosques in Jeddah is reported to be 950 which is considered to be among the largest found within any city in the Kingdom. Table 2.2 shows statistics about the development of Jeddah's existing mosques[5,6].

Table 2.1 The number of mosques in major regions in Saudi Arabia

Region	no. of mosques
Eastern	3000
Middle	8610
Northern	1450
Western	3606
(Jeddah, Madinah and Makkah)	

Sources: 1. K. Husaini, "Ihtimmam Khadim Alharamain Alsharifain Bibbyout Allah Tajawaz Hodood Almumlakah" (Care of the Custodiun of the Two Holy Mosques on God's Houses has Crossed the Kingdom's Boundary). ***Okaz,*** no. 9598, 7 November 1992, p. 11.

2. S. Bin Talib, "Hokoomut Almumlakah Toli Ehtimamun Biimar Biyout Allah" (The Government of Saudi Arabia do care for the Construction of Houses of God). ***Okaz,*** no. 9612, 21 November 1992, p. 7 and 12.

Table 2.2 Statistics on the development of Jeddah's existing mosques

Dates	no. of mosques
1964	59
1974	223
1981	460
1991	950

Sources: 1. The editor, "Jeddah fi mutla'a alqurn alkhamis Ashar" (Jeddah in the Beginning of the Fifteenth Century). ***Iqra'a***, Special Edition, April 1981, p. 200.

2. K. Husaini, 1992, op. cit., p. 11.

2.1 The construction, operation and installation of air conditioned mosques

2.1.1 Government and private sector involvement

The building of air conditioned mosques in Jeddah, as in all cities in the Kingdom of Saudi Arabia is sponsored by the Government and the private sector. The Government office for this work was represented by the Ministry of Hajj and Awkaf until 1992 and recently was annexed to the new Ministry of Islamic Affairs in 1993. The private sector is represented mainly by citizens who are either rich individuals or middle to high income people who jointly sponsor this type of activity.

The government pays the cost of these air conditioned mosques and offers grants to the private sector (if they wish) to build new mosques[7].

Several regional branches of this Ministry under the name of "The General Directorate of Awkaf and Mosques" are normally established in larger cities to issue the necessary permits for mosque construction and operation.

It is also the duty of this Government office to pay all the operational costs of those mosques built by the Government. Such costs include the monthly salaries of staff in every mosque, consisting of the Imam (Leader of the Prayers), Muáddin (the one who calls for the prayers) and the servitor (the person who is responsible for keeping the mosque tidy and clean), and the water and electricity bills.

In the case of those mosques built and operated by the private sector, a committee of two or three people is responsible for paying operational costs either from their own money or public donations.

When these operational costs cannot be met by the private sector once the mosque is built, the operational side is left to the government office as the best alternative.

Both sectors are doing their best to provide these mosques with carpets, cabinets for the Holy Book, The Quran, and electric appliances. As outlined above, typical appliances includes fans, lights, sound amplifier system, water coolers and air conditioners.

2.1.2 Development of appliance installation in existing mosques

The provision of electric appliances (of fans, sound amplifiers and lights) in Jeddah's mosques dates from the first introduction of electricity in the city in the 1940s. This set the pattern for all mosques built until 1966 when for the first time air conditioning was introduced[8]. It has been only recently that the use of water coolers inside the mosque was introduced. At the present time all Jeddah's mosques use various numbers of fans and water coolers, with fans being used in more than 90% of cases and water coolers being used in approximately 60% of cases.

This situation applies to both the Government and private sector mosques. This scenario does not only occur in modern mosques but also applies to the older ones, even in those mosques which were built hundreds of years ago. The best examples of these are the traditional mosques of Hanafi, Shafi and Mimar where all appliances have been provided recently (see Fig. 2.1). There is a growing tendency by the government

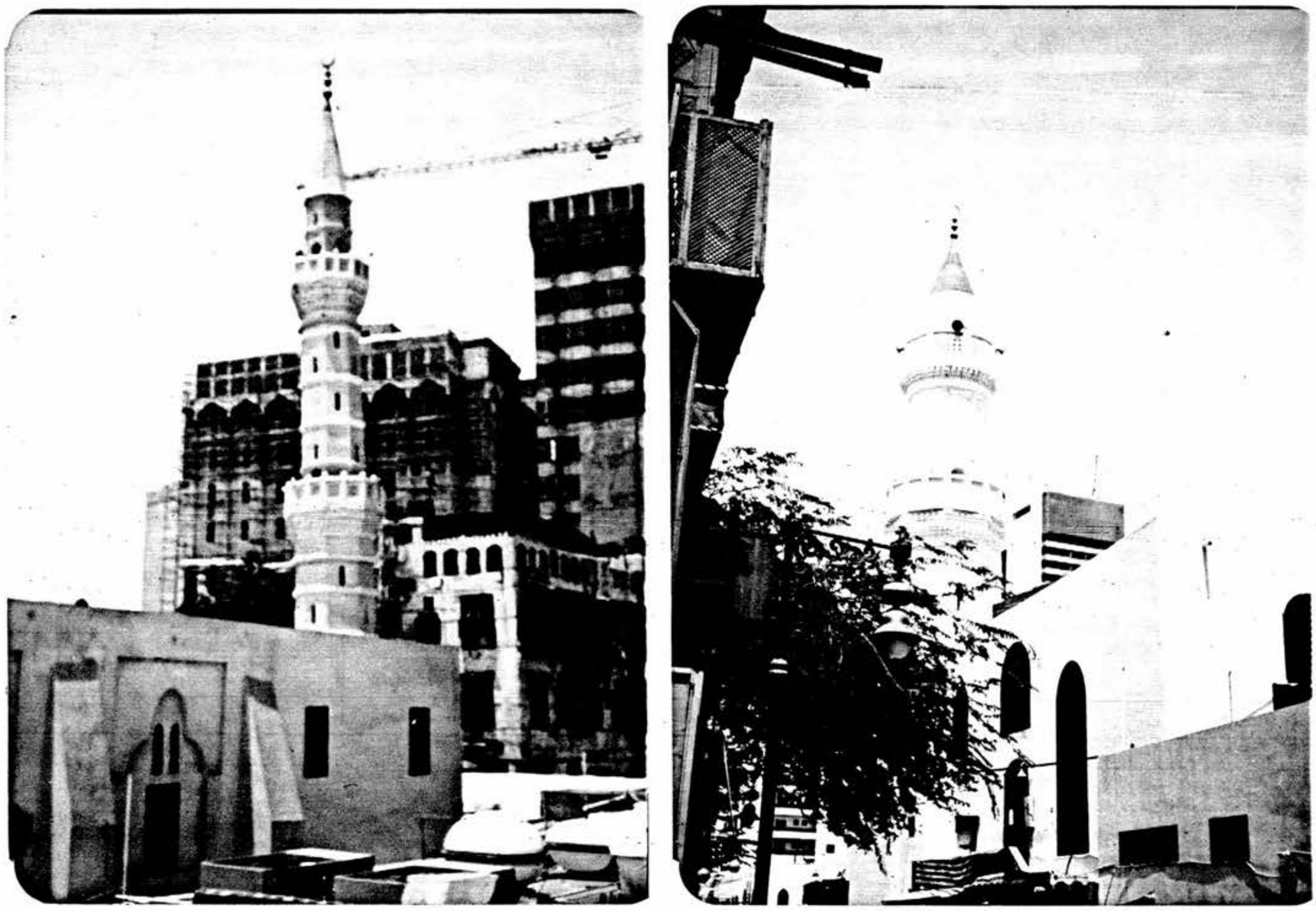

Figure 2.1 Old mosques in Jeddah recently equipped with modern appliances of lamps, water coolers, sound amplifiers, fans and air conditioners.

to supply those mosques with electricity and with air conditioners[9].

2.1.3 Notes on the recent trend in using air conditioners in mosques

It is interesting to find the reasons behind the use of air conditioners in mosques. The main reason behind this trend is that the indoor climate of the existing mosque does not have the capability of providing appropriate atmosphere for the worshippers to pray comfortably. This is as a result of two main factors. First, is the obvious factor relating to the increasingly hotter climate experienced together with heat reflected from the modern urban developments such as concrete buildings, asphalt roads and streets, paved walkways and lack of greenery in addition to the free open design of the old mosques and the poor thermal design of the new ones.

Secondly are the factors relating to our comfort levels. The author suspects that our current comfort levels differ from the past[10]. We are accustomed to the cold interior climates offered by air conditioners as we have been using this system for sometime and which have been present in our daily life activities from the work place to markets, our houses and finally our mosques.

The widespread use of air conditioners in mosques can be viewed from two main perspectives. The first one is connected with air conditioners themselves. They are very effective in cooling the mosques, experience minimal mechanical problems and require little maintenance, and above all they are affordably priced (5000 to 10000 Saudi Riyals or 860 to 1720 Sterling pounds for each unit).

The second factor is related to finance; the Government has granted substantial amounts of money to purchase thousands of air conditioners for mosques with electricity[11]. Moreover, most air conditioning dealers in the Kingdom are willing to offer large discounts when selling their systems to mosques hoping to get more rewards from God.

2.1.4 User's status

Five prayers are compulsory for every Moslem male and female, not mentally ill and over seven years old. Thus in mosques, worshippers are a mixture of old people, young adults and children. The female presence in Jeddah's mosques is limited to fewer prayers per week and sometimes in some mosques on a monthly basis. Their attendance can be noticed during the holy month of Ramadan mainly during the late prayers. Women should not mix with men during the prayer[12], therefore special compartments are created for them in most of Jeddah's mosques.

2.1.5 Main activities in Jeddah's air conditioned mosques

There are three main activities which occur in Jeddah's air conditioned mosques. These activities are praying, lecturing and teaching of the Quran (the Holy Book) and Islamic affairs. The occurrence of the last two activities tend to vary from mosque to mosque. Both mainly occur in larger mosques. The lecture normally lasts for an hour once a month and the teaching of The Quran occurs three times a week, usually after the Asr prayer for one hour or between the Magrib and Isha prayers. The principal activity of concern in this research is praying because it is the primary feature which is shared by all Jeddah's mosques and further information is needed on this topic; in particular, the actual performance of the prayers, the numbers and kinds of prayers offered in these air conditioned mosques. The former will be discussed in detail in the next chapter and the latter will be fully addressed here.

Table 2.3 clarifies a set of information regarding the numbers and kinds of prayers in air conditioned mosques which are the case for any other non air conditioned ones. The principal prayers performed in mosques are nine; six of which are compulsory; five are of daily occurrence (Fajr, Duhur, Asr, Magrib and Isha'a) and one on a weekly basis known as the Jum'a prayer. Three are non-compulsory ones, two of which are on a yearly basis, two Eids prayers and the Taraweeh prayer are in the whole month of Ramadan. One occurs occasionally as the Janazah prayer (Funeral Prayer). Eight of these principal prayers are characterised by a set of bowing except the "Janazah" prayer. Each prayer has a specific number of bows known as Fard. A set of sunnah prayers (secondary prayers), specified with a particularly number of bows, is performed before and/or after the principal prayers in sight of the prophet instructions.

2.1.6 Justification of the appliances' use in mosque contexts

The purpose of appliances and the degree of their presence in mosques will be discussed later in section 3 where every appliance is fully analysed.

2.1.7 Typical times of use

One of the fundamental issues in understanding the magnitude and pattern of the use of electricity in existing air conditioned mosques is to discuss in depth the total

Table 2.3 Different types of prayers performed in mosque

Prayer name	*Sunnah* before	*Fard* no.of bows	*Sunnah* After	Total
Compulsory prayers - once daily				
Fajr	2	2	0	4
Duhur	4	4	4	12
Asr	4	4	0	8
Magrib	0	3	4	7
Isha'a	4	4	9	17
Compulsory prayers - once weekly				
Jum'a	4	2	8	14
Non-compulsory prayers - twice yearly				
Eid		2		2
Non-compulsory prayers - once yearly				
Taraweeh			20	20
Non-compulsory prayers - occasionally				
Funeral	no bowing			

Fard : Prayers which are clearly ordained by Allah.

Sunnah : Prayers introduced by the Holy Prophet where more or extra deeds will be rewarded to any one who does them without any punishment to the one who does not perform them.

times of use in these buildings limited to the prayers as a typical feature in Jeddah's mosques. Several important subjects are involved. These are times of opening, calling for the prayers (Adan), calling for the beginning of the prayers, performing the prayers and closing the mosque. These are shown in schematic outline in Fig. 2.2.

The Ministry of Haj and Awkaf together with other government offices have developed a time schedule to call for the prayers (Adan) for most cities in the Kingdom during the whole year[13](see Fig. 2.3). These time schedules are published in a calendar known as 'Umm al-Qura Calendar'. Instructions have been put forward to all the mosques in the Kingdom to follow these published timetables to call for the prayers indicating the time difference for those cities not shown in the calendar. Thus there is a very clear understanding of the times most mosque are occupied.

The times of opening the mosques are typically found to range from 10 to 15 minutes prior to Adan (calling for prayers stated above) and the switching on of these appliances is carried out instantaneously.

The starting times for the performance of the prayers are always after the Adan. Table 2 4 shows the different time duration specified for each prayer[14].

The actual time of each prayer tends to differ from mosque to mosque and from prayer to prayer due to the different leader performances in every prayer. Experience indicates that the time duration of each prayer is as follows:

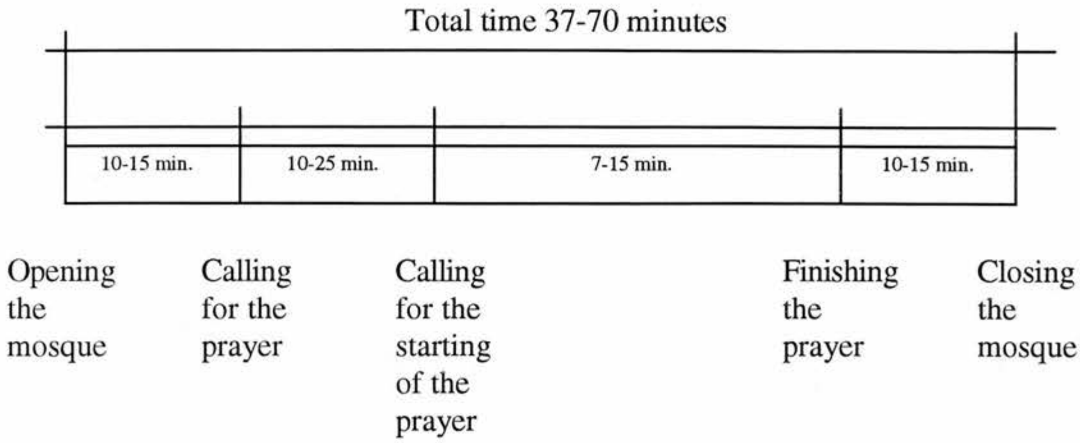

Figure 2.2 The typical scenarios relating to the use of mosques in every prayer.

City	Fajr	Ishraq	Duhur	Asr	Magrib	Isha'a
Makkah	4:23	5:50	12:27	3:43	7:05	8:35
Madinah	4:15	5:46	12:28	3:52	7:11	8:41
Riyadh	3:46	5:17	12:00	3:24	6:43	8:13
Dammam	3:27	5:00	11:46	3:15	6:33	8:03
Boraidah	3:52	5:25	12:11	3:39	6:57	8:27
Tabook	4:15	5:50	12:40	4:13	7:31	9:01
Arar	3:48	5:27	12:22	4:01	7:18	8:48
Abha	4:20	5:45	12:16	3:32	6:49	8:19
Jezan	4:23	5:47	12:16	3:33	6:47	8:17

Source: Umm Alqura Calendar (the official Government calendar)

Figure 2.3 Daily prayer timetable for major cities in the Kingdom for July 23, 1990.

Table 2.4 Different time duration specified for every prayer

Prayer	Duration
Farj	25 minutes after Adan
Duhur	15 minutes after Adan
Asr	15 minutes after Adan
Magrib	10 minutes after Adan
Isha'a	20 minutes after Adan

Source: A. Al Mubarak, an official letter to each mosque in Jeddah to follow the Instructions laid down for the *Iqama* (starting) time of each Prayer, 1989.

Fajr		10 minutes (min) to 15 minutes (max)
Duhur		
	daily	10 minutes (min) to 15 minutes (max)
	once a week	30 minutes (min) to 45 minutes (max)
Asr		10 minutes (min) to 15 minutes (max)
Magrib		7 minutes (min) to 10 minutes (max)
Isha'a		
	11 months	10 minutes (min) to 15 minutes (max)
	one month	40 minutes (min) to 50 minutes (max)

The Friday prayer (Duhur prayer every Friday) has the same time length in performance except there is a talk (lecture) delivered in two stages. The Taraweeh prayers are normally performed in the Holy month of Ramadan and would last for 40 to 50 minutes after the Isha'a prayer.

The time of closing the mosque and the switching off of its appliances ranges between 10 to 15 minutes after the prayer has finished.

Based on the above times for the different scenarios involved in each prayer the total typical time of use for any mosque in Jeddah is as follows:

Prayer	Minimum (minutes)	Maximum (minutes)
Fajr	55	70
Duhur	45	60
	60	90 once a week (Jum'a)
Asr	45	60
Magrib	37	50
Isha'a	50	65 for 11 months
	90	115 for 1 month (Holy Ramadan)

2.2 Physical characteristics of existing air conditioned mosques

The intention in this section is to give general ideas about the physical characteristics of the existing mosques in which air conditioners are used.

2.2.1 Types and locations

Jeddah's air conditioned mosques can be classified in three categories depending upon the types of prayers performed. The first category are those mosques where Eid, Friday and daily prayers are performed. They represent 1% of the total air conditioned mosques in Jeddah. Secondly are those mosques performing the Friday and daily prayers constituting 85% of the total[15]. Finally, mosques for daily prayers only represent 14% of the total.

The locations of these air conditioned mosques are not limited to particular elements of urban developments of residential and commercial domain. Presently they cover various types of urban development as follows:

i) In the residential sector: air conditioned mosques can be found in mass housing projects (Fig. 2.4) and part of the richer residential complexes; Prince Torki and Prince Salaman are good examples.

ii) In the recreational sector: they are spread along the beach, some of which have won the Aga Khan Award for Islamic architecture. Moreover, they exist for the first time in sport club complexes of Al-Ahli and Al-Ettihad.

iii) In other sectors; air conditioned mosques now exist in the government office, commercial centres, educational developments, industrial areas, health projects and Jeddah's international airport.

2.2.2 Components of existing air conditioned mosques

Existing air conditioned mosques in Jeddah consist of three types of buildings; the prayer hall, the residences and the services (Fig. 2.5). Each of these parts will be discussed independently.

Figure 2.4 Air conditioned mosques in mass housing projects

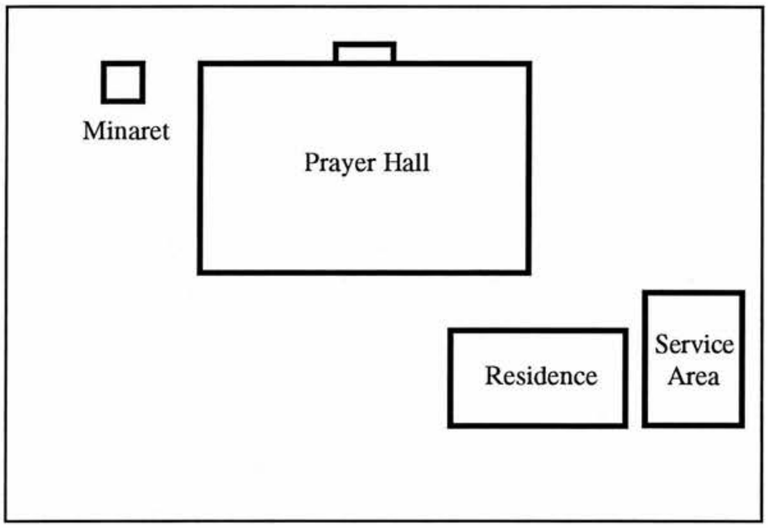

Figure 2.5 Typical principal elements in existing air conditioned mosque complexes in Jeddah.

2.2.2.1 The prayer hall

The prayer hall or sanctuary forms the main area where the prayers take place and where worshippers stand in parallel rows. In Jeddah's mosques these halls are commonly squarish or rectangular in shape. Very few examples are found in hexagonal and circular layouts. Prayer halls in some mosques are composed of two sub-areas: the main lower halls and an additional mezzanine floor. The latter is commonly located in the back and it may be found in two mezzanine floors parallel to each other. In some cases this mezzanine floor is used as a female prayer hall and in those mosques with no mezzanine, a separate room, either attached or detached to the main prayer hall is constructed. On the other hand, part of the main prayer hall is divided to provide a female prayer section. This part is either completely or partially physically separated with the use of partitions. An extension of the prayer hall might be, in some mosques, in an area called a Sahn (courtyard). It is the uncovered area of the mosque and occasionally used for prayers when there are large congregations.

The sahn takes two forms in Jeddah's mosques; either as a dominant feature in the middle or at the rear of the prayer hall (see fig. 2.6) in three different layouts. In fact, only very limited numbers of mosques in Jeddah have sahn and if it exists the current trend is to cover the area and link it with the prayer hall.

Every prayer hall must be directed to the Kaaba in Macca. This direction is called the *'Qibla'* and the front wall of the prayer hall is consequently called the '*Qibla* wall'.

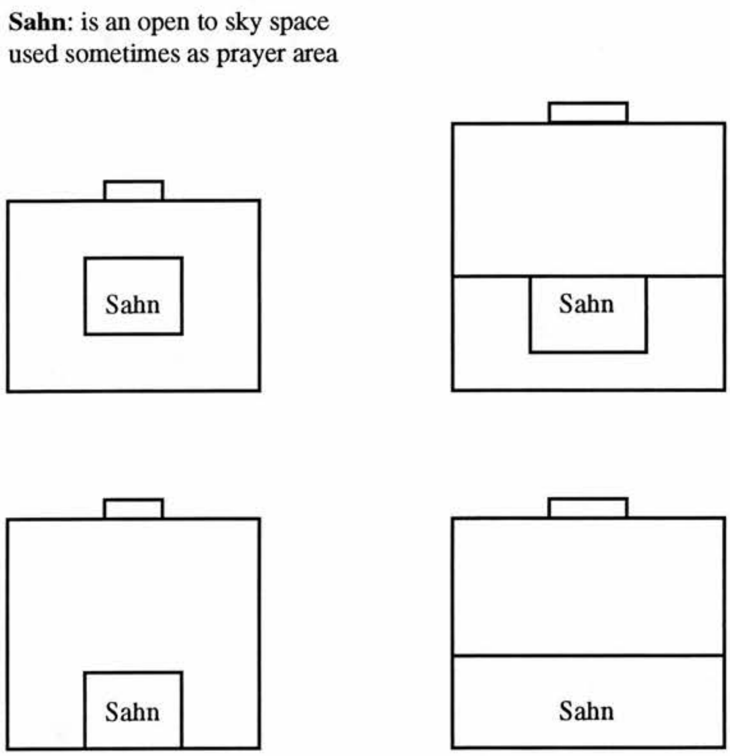

Figure 2.6 Sahn (courtyard) layouts in existing air conditioned mosques in Jeddah.

A 'mihrab' is normally located in the centre of the Qibla wall. It is a niche serving as a place of prayer for the *'Imam'*, the one who leads the prayer. The shape of this place tends to vary from mosque to mosque with a semi-circular or polygonal layout. In some mosques the mibrabs are extensively decorated with marble and mosaics and contained plasterwork, geometric patterns and calligraphy.

The 'minbar' or pulpit is the second important element in the prayer hall. It is normally located to the right of the mihrab. Originally it was an elevated area where the Imam gives the Khutba (Friday sermon). It is either constructed with a hidden concrete stair (namely 10-15 steps) which lead to a small platform or a wooden piece of furniture perpendicular to the qibla wall. In most of Jeddah's existing mosques, the minbar is commonly found in a form of a projecting balcony made of concrete.

In addition to these primary elements commonly found in almost all prayer halls in existing air conditioned mosques, a secondary element of a minaret is found attached to or detached from the prayer hall. The minaret has developed from the need for a height from which the adan (call for prayer) is given. Originally, it was an elevated part in the prophet mosque in the city of Madina and later developed in a different form. Although the minarets are not obligatory in mosques nor is their location, they tend to occur in every existing air-conditioned mosque in Jeddah with different heights, locations and cross-sections. As far as their numbers in a mosque is concerned, very few mosques in Jeddah have two minarets and the majority have one. Another element is the presence of either a dome or a clerestory in the roof of the prayer hall. The latter has a straight or gable form and is widely used in Jeddah's mosques for economic reasons (see Fig. 2.7).

2.2.2.2 Services quarter

Services areas are those related to activities such as ablutions, bathing and toileting. These areas are normally accommodated in a separate structure far from the prayer hall.

2.2.2.3 Residential complex

Most of Jeddah's existing mosques accommodate private residences for the Imam (the leader of the prayers), the Muaddin (the person who calls for the prayers) and the servitor (one person whose duties are to keep the mosque clean and tidy and to take care of the operation of the appliances). Commonly these residences are found in a form of two storey buildings detached from the prayer hall and in many instances these residences are built above the services quarter.

2.2.3 Main architectural features of existing mosques

The design of these air conditioned existing mosques are either a government prototype design, which was developed in 1975 and modified later in 1988[16], or a non government one developed by local or foreign architectural firms.

The main architectural features of the existing mosques are the layout and the

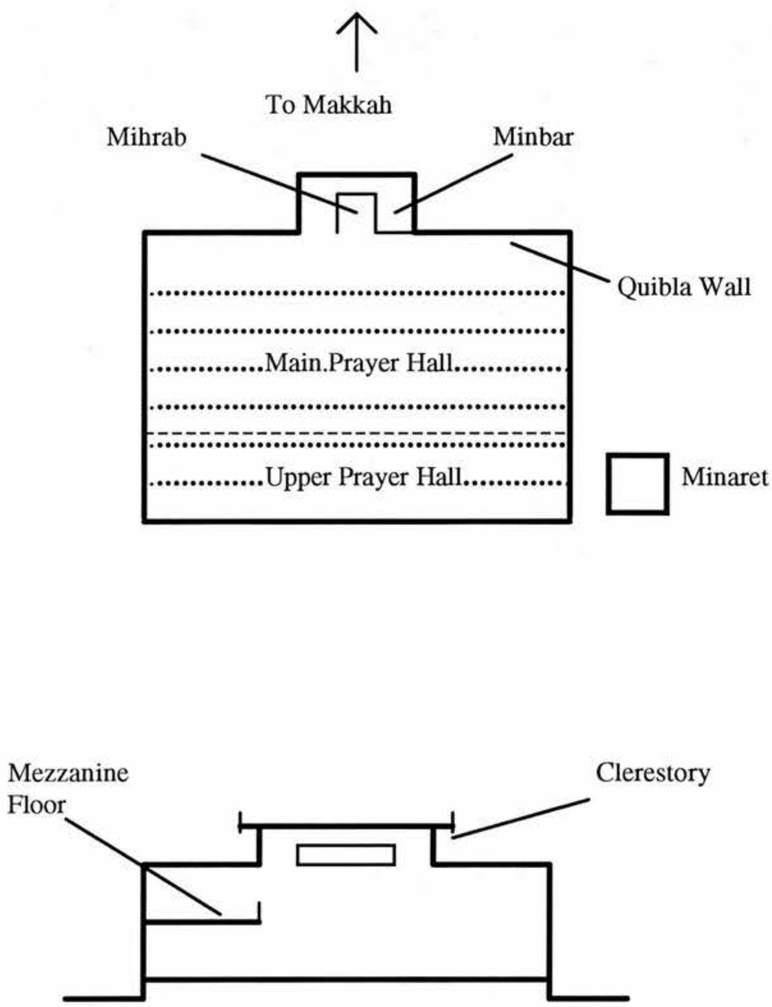

Figure 2.7 Typical elements within the prayer hall domain.

volume. The main layout of these air conditioned mosques are of two types:

a. Those with a courtyard (sahn)

b. Those with no courtyard

The courtyard (sahn) are either central, such as in the King Saud and Al-Harithy mosques or non-central like Al-Juffali, Shafi and Hanafi mosques. The non-courtyard mosque type represents the majority of Jeddah's air conditioned mosques. Within the context of new appliances used in the mosques, the appearance of courtyards in existing mosques has started to diminish due to the fact that a major heat drain from these courtyards towards the prayer hall is expected and at the same time a large volume of cool air is expected to escape through them. Many existing courtyard mosques have covered their courtyard with either canvas or transparent pyramids.

As far as the volume of these existing mosques is concerned, all air conditioned mosques in Jeddah are of large volumes. They can be classified into four types based on the volumes of the prayer halls: where the height should not be less than 6m[17]. Type no. 3 is the dominant type in the city.

Type no.	Volume
1	more than 50,000m^3
2	more than 12,000 m^3
3	2,000 - 9,000 m^3
4	1000 m^3

Definitely, with such a building characterised with larger volumes and complexity of usage in terms of frequency, duration, etc., as discussed in the previous section, the demand for greater numbers of air conditioning appliances is unquestionable.

2.2.4 Building materials and structural systems

Building materials in existing air conditioned mosques are of different types. They can be classified into four major groups based on their use in roofs and ceilings, walls, floors and openings as follows:

I)	roofs	old mosques modern mosques	wood, mats, earth, mud reinforced concrete, in sulation (asphalt sheets) earth, gypsum tiles.
	ceiling	old mosques modern mosques	wood cladding with suspended ceiling of gypsum or plaster painted
ii)	walls	old mosques	coral stones, lime whitewashed
		modern mosques	concrete blocks, red fired blocks, terra cotta, concrete wall covering, cladding with painted plaster or marble tiles.
iii)	floor	old mosques	gypsum tiles, concrete, wool carpet
		modern mosques	gypsum tiles, concrete and wool carpets with no underlay.
iv)	openings (window and doors)		wood, aluminium frames and glass.

As far as the structural systems of these existing mosques is concerned, three types of systems are used:

a. Load bearing walls.

b. Reinforced concrete skeleton frames.

c. Precast concrete.

The predominant system is reinforced concrete due to economic reasons with a very few applying the other two systems which cost more in terms of materials and skilled labour.

In this section the physical characteristics of existing air conditioned mosques in Jeddah have been discussed as an important part in understanding the context in which these installations are operated.

2.3 Typical electric appliances used in existing air conditioned mosques

In this section, five electric appliances will be discussed. The discussion will cover the different aspects of functions, location, types and usage, patterns, purposes and time of use on a monthly basis.

2.3.1 Lamps or lighting units

These are used to light the mosque's interior and exterior. As far as the daily prayers are concerned three prayers (Fajr, Magrib and Isha'a) are performed in different times on which the natural light is either weak as is the case in Magrib prayer (sunset prayer) or not at all present, as in the Fajr (Dawn prayer) and Isha'a prayers (late night). Therefore there is a strong need to provide sufficient lights for these three prayers.

These units are placed inside the prayer hall and outside it. Commonly, interior light units tend to be more intensive and bigger in size and number than the exterior ones and distributed around the prayer hall. The exterior ones are used to light mainly the entrances and the minaret. Two types are used in mosques:

a) Fluorescent lamps; 1800 mm long, 40-100 watts and placed on either the ceiling or on the interior walls.

b) Bulb type lamps; mainly in small chandelier form suspended from the ceiling and of 40-100 watts.

At Fajr, Magrib and Isha'a prayers fluorescent lamps are used all year round and leave other bulb lamps for special occasions like the Friday nights, Eid feast and Ramadan nights prayers.

Based on the time needed for the three prayers of Fajr, Magrib and Isha'a, (section 2.1.7) the total time of use for these lamps are calculated and found to range between 142 to 185 minutes on a daily basis. Therefore, the total time for monthly use is expected to be 71-92.5 hours.

2.3.2 Sound amplifiers

Effective electric sound systems are used to send the sound of Imam, Muáddin and the lecturer to greater distances around and inside the mosque. The system consists of amplifier, microphones and loudspeakers (see Fig. 2.8). The amplifier, the control unit, is connected with at least two microphones and 10-15 loudspeakers. This amplifier is of three types 30, 60 and 120 watts[18] and it is normally located at a close distance to the Mihrab (place where the leader of the prayer stands) or under the Minbar. The loudspeakers are of two types: the cabinet and the horn types. The former are scattered around the prayer hall's walls while the latter are placed outside mainly in the upper parts of the minaret and in each corner in some mosques.

The use of this system is in two stages in each prayer. The system is put on with the first moment of each prayer i.e. to call for the prayer and will be turned off after this call is completed. This call may last from 2-5 minutes. Then the system will be put on again to call for the beginning of the prayer and remains on during the prayer and is turned off directly after the prayer is completed.

During the Friday sermon, the system is always kept on during the lecture and is turned off as the Friday prayer finishes.

Table 2.5 shows the expected time duration of the system use on a daily basis and on Fridays. Total time used of the system during a month is expected to be 1865 to 2595 minutes equal to 31.08 to 43.25 hours.

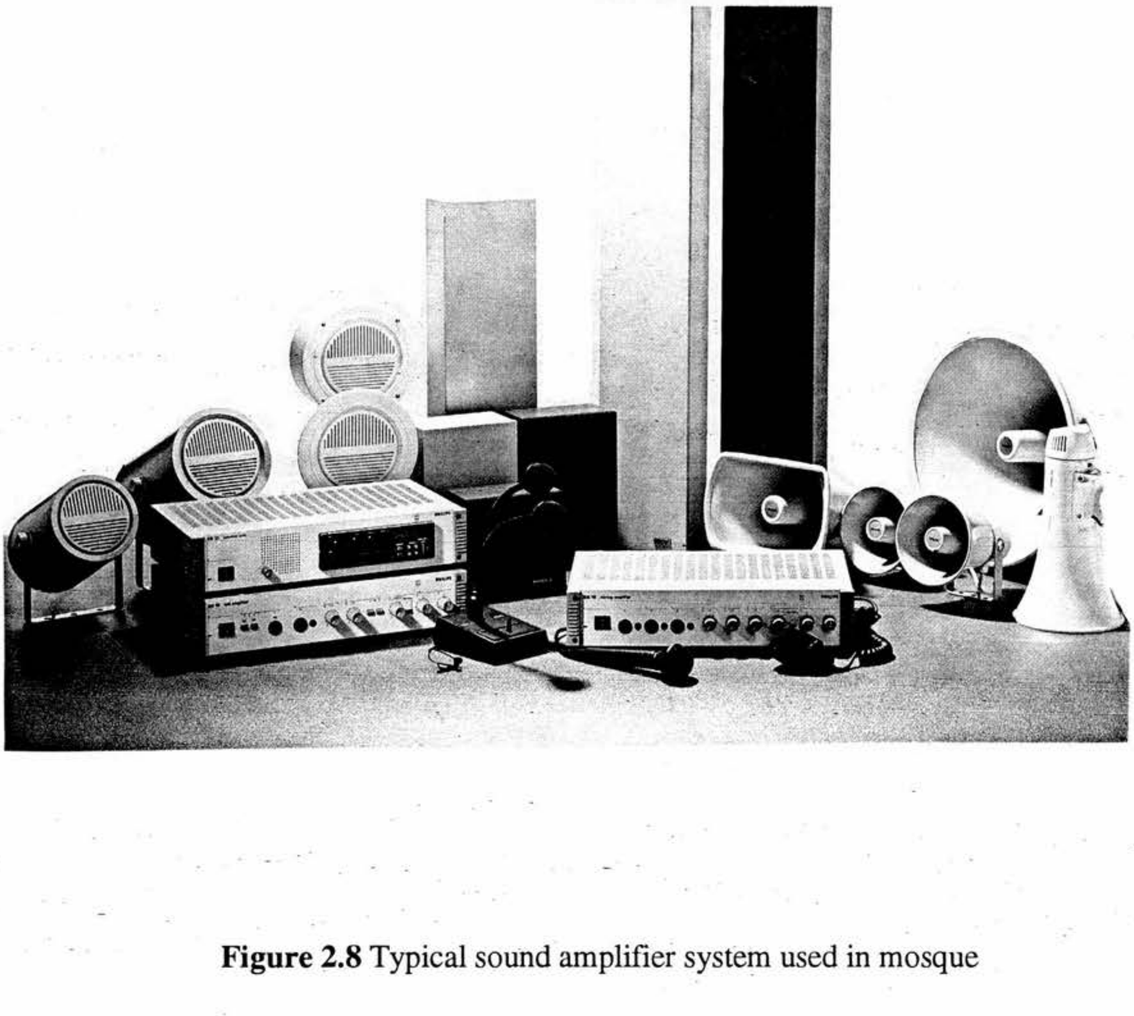

Figure 2.8 Typical sound amplifier system used in mosque

Table 2.5 The expected time duration of the sound amplifier system usage on daily basis and on Fridays (in minutes)

	Daily		Friday	
Prayers	Adan	Igama & actual prayer	Adan	Igama & actual prayer
Fajr	2-5	10-15	2-5	10-15
Duhur	2-5	10-15	2-5	30-45
Asr	2-5	10-15	2-5	10-15
Magrib	2-5	7-10	2-5	7-10
Isha'a	2-5	10-15	2-5	10-15
26 days	325	1222-1820	50	268-400

2.3.3 Water coolers[19]

Water coolers are used to cool the water. They appeared recently inside the prayer hall. These coolers are used to cool both fresh water and the holy water of Zamzam (the only source of this water is a well next to the Holy Kába in Makkah). The common type is the 25 litre type (see fig 2.9) and their sizes and weights are handy which ease their presence in large numbers (5-10) inside the prayer hall. In general, these coolers are limited to a few mosques in Jeddah, but their use is increasing.

Commonly they are put on as the mosque opens and switched off as the mosque closes. This scenario occurs all year round and for all the prayers. Table 2.6 shows the time patterns for 26 days and 4 Fridays.

The total monthly time of use for the water cooler in a mosque is expected to range between 117 to 154.5 hours.

2.3.4 Fans

Electric fans are used in the majority of existing mosques in Jeddah. They are used to provide air in the prayer halls. Three types are commonly used; the ceiling, wall and floor or stand fans. The most common one used is the ceiling fan. It consists of three parts; the condenser motor, speed control regulator and metal blades[20](see fig. 2.10). It can be found in three different sizes of 56", 48" and 36". They are placed

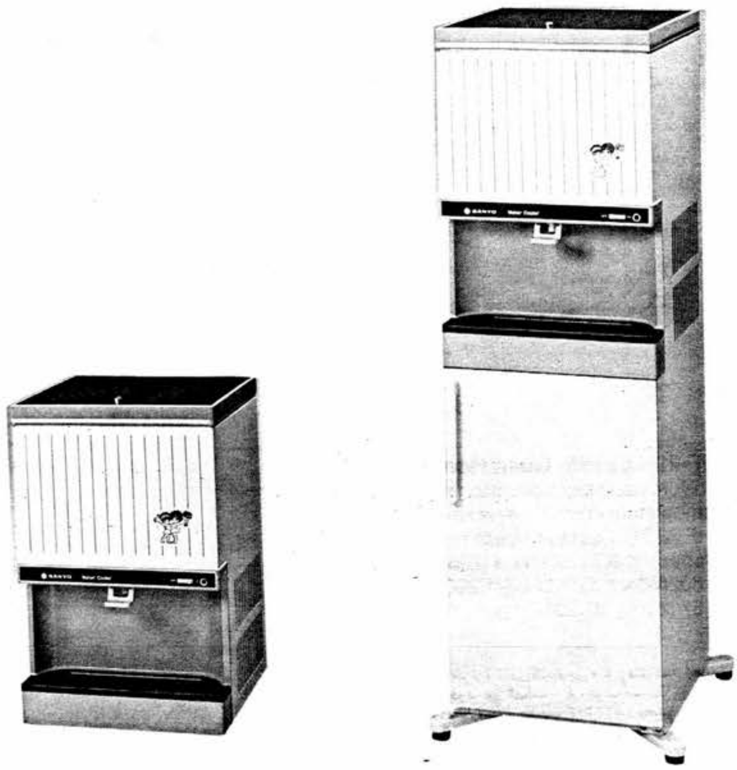

Figure 2.9 25 litre water cooler used to cool the holy water of *'Zamzam'* springs in a well next to the holy *Káaba* in Makkah.

Table 2.6 The expected time duration of the water cooler on daily basis and on Fridays (in minutes)

Prayer	26 days	4 Fridays
Fajr	55-70	55-70
Duhur	45-60	60-90
Asr	45-60	45-60
Magrib	37-50	37-50
Isha'a	50-65	50-65
Total	6032-7930	988-1340

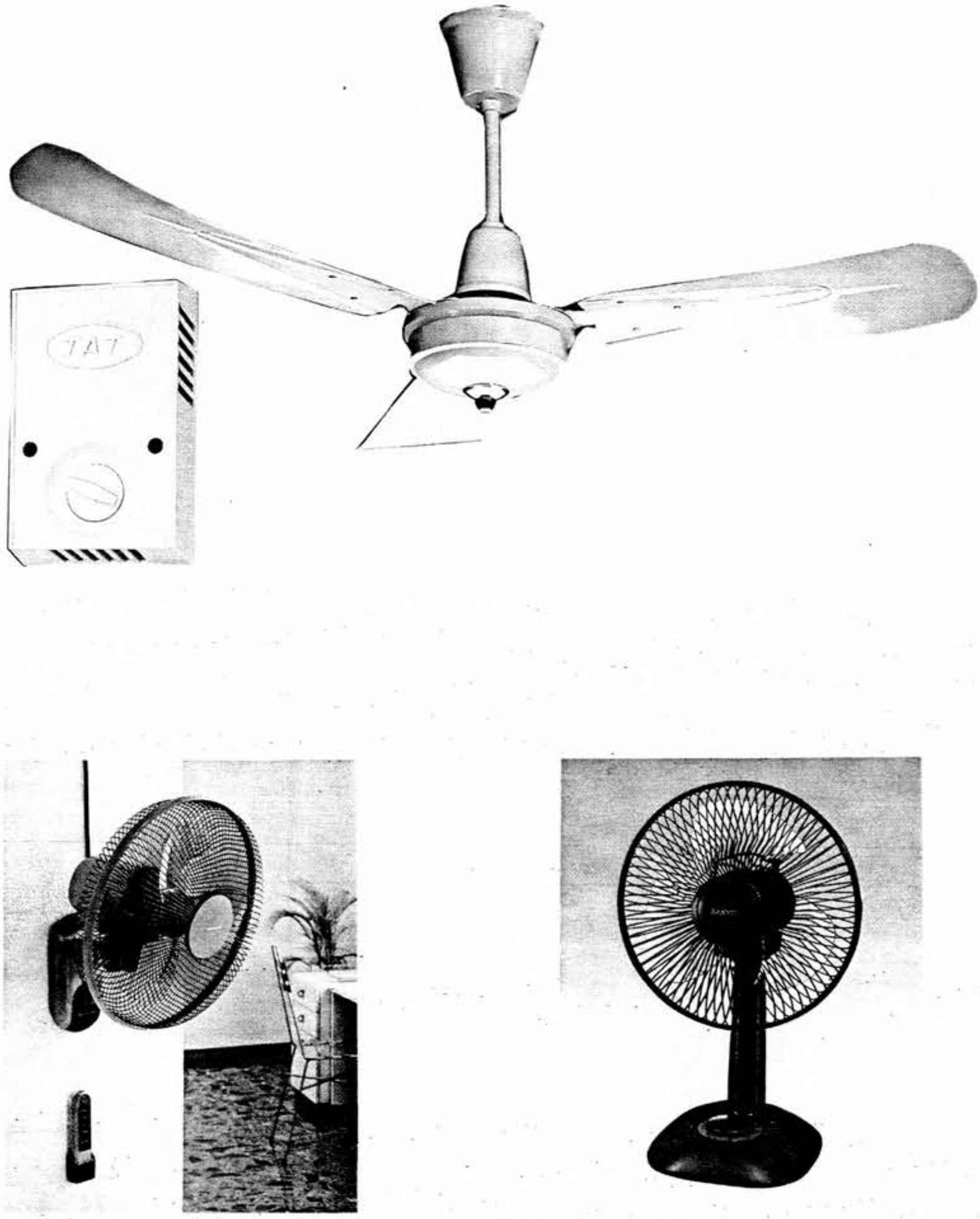

Figure 2.10 Fans commonly used in existing air conditioned mosques.

4 to 5 metres apart all over the prayer hall ranging between 10 to 15 in number.

The pattern of use for this machine is strongly influenced by the climatic conditions. In most cases they are put on all year round for all the prayers except for a few days in the winter. Sometimes, particularly under moderate climatic conditions, only half of them are put in operation. Like water coolers, fans are always switched on as the mosque opens and are turned off once the mosque closes. It is the intention of every mosque to keep the speed of these fans constant. Normally a moderate speed (speed no. 4) is preferred.

Table 2.7 explains the time of use in 26 days and 4 Fridays. The expected time of use for the fans in mosques is 117 to 154.5 hours.

2.3.5 Air Conditioners

Air conditioners are electric machines which provide cool air. They are used in mosques to provide a cold climate in the prayer hall needed for the worshippers' comfort[21] during the hot seasons. Three types are commonly used in Jeddah's existing mosques; mounted, split and window package types (see fig. 2.11). The component of each of these types will be discussed in detail in the next chapters. The central and floor mounted split type are very popular in these mosques because both are effective in providing the acceptable levels of coolness in a shorter time than the window type. In fact, the floor mounted one is the type most used due to the ease of installation and it is cheaper in cost. Numbers of 4 to 6 of 50,000 BTU (cooling capacity), are widely

Table 2.7 The expected time of use of fans in 26 days and 4 Fridays (in minutes)

prayers	26 days	4 Fridays
Fajr	55-70	55-70
Duhur	45-60	60-90
Asr	45-60	45-60
Magrib	37-50	37-50
Isha'a	50-65	50-65
Total	6032-7930	988-1340

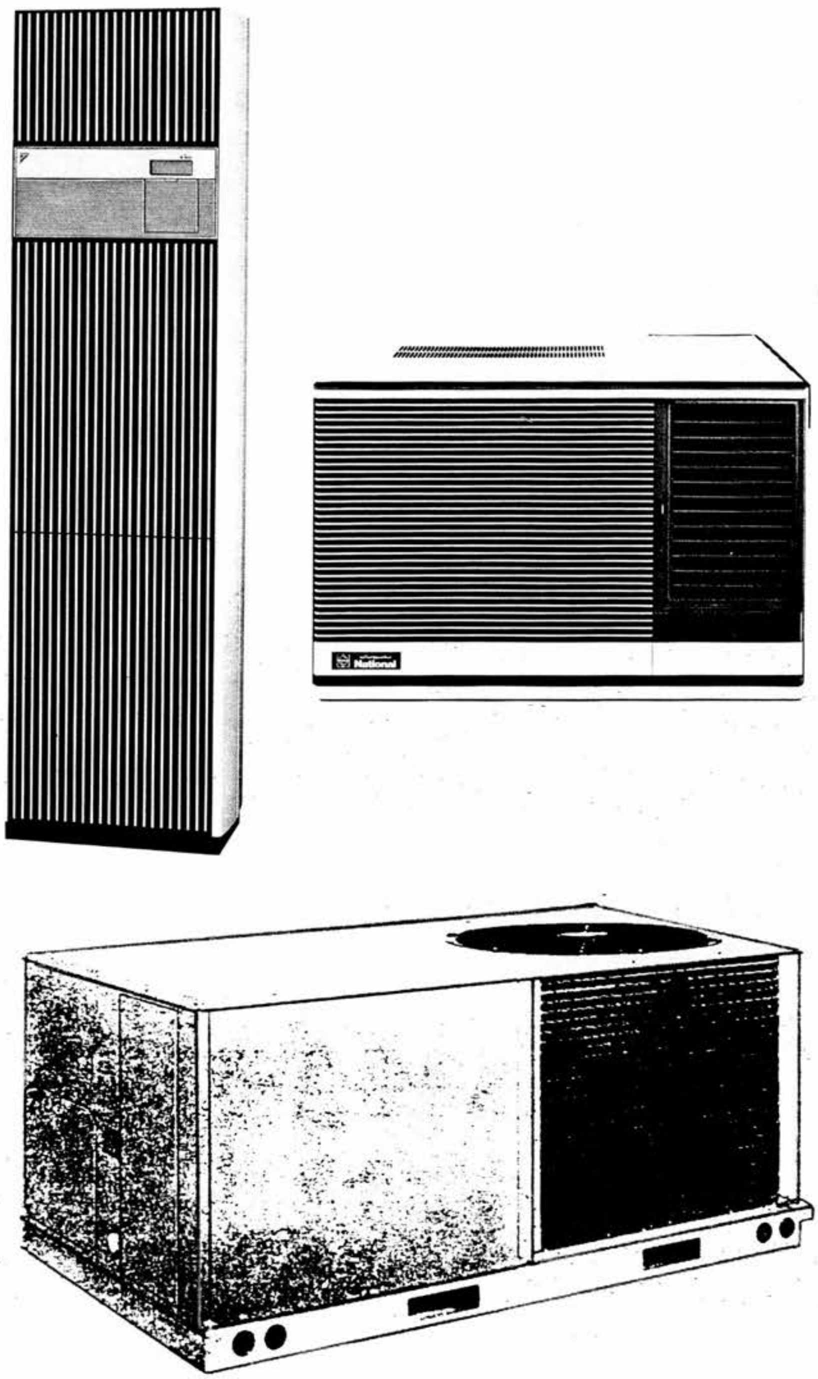

Figure 2.11 Typical types of air conditioners used in mosques

used, placed around the prayer hall.

As far as the pattern of use is concerned, normally the system is switched on and off with the opening and closing of the mosque for each prayer (10 to 15 minutes prior to the prayer's call time and 10 to 15 minutes after the prayer ends). In addition, part of the system might be put on under moderate climatic conditions. Normally, for at least eight continuous months, the whole system is operated. Furthermore, in almost all mosques both air conditioners and fans are put on together in order to cool the prayer hall quickly.

Finally, the thermostat of these air conditioners are kept at 26°C and a note is put on in every unit for the public not to alter this preferred temperature. Similar to fans and water coolers, the total monthly time of use for the air conditioners in the mosque is expected to be from 117 to 154.5 hours.

2.4 Estimation of energy, CO_2 and CFCs emissions from the appliances typically used in existing air conditioned mosques

2.4.1 Emissions of carbon dioxide

The approximate amount of CO_2 emission can be estimated by (1) calculating the electricity consumption of the appliances typically used in existing air conditioned mosques and (2) multiplying these consumption figures by 0.059 (It was estimated that for each unit of electricity used by the consumer, the expected amount of CO_2 emitted is 214 Kg per gig joul[22] or 0.059 Kg per Kilowatt hour (Kwh = Mega joul / 3.6)[23]. A direct simple arithmetic technique is selected for this purpose.

$$\mathbf{TEC = MC \times TT \times NA \times 0.059} \qquad \text{...(2.1)}$$

Where;

TEC = the expected electricity consumption of the appliance in existing air conditioned mosques

MC = the mean consumption of the appliance per hour[24,25,26]

TT = the total time of use for the appliance per month

NA = typical number of the appliance in existing mosque

The use of these appliances is influenced by seasonal conditions in a form of variations in time and the number of appliances used. Thus, the author has included the expected monthly consumption under extreme conditions or summer and winter.

Table 2.8 summarises the expected emissions of CO_2 from these appliances shown in numerical form. These numbers have then transferred to graph form (see fig 2.12) which will show graphically the levels of emissions of these appliances.

From the graph, we notice that air conditioners (with the three types commonly used) are responsible for most of the CO_2 emissions in existing air conditioned mosques in Jeddah during summer and winter times. Furthermore, it can be clearly seen that the extreme difference between the amount of CO_2 emissions as related to these air conditioners compared to the others occurs during summer and tends to

Table 2.8 Summary of expected CO_2 and CFCs emissions from appliances typically used in existing air conditioned mosques in Jeddah.

Electrical appliance	Sound system	Lighting 100 W	Fans 100 W	Water cooler	Air conditioners		
					Window 18000	Floor 50000	Central 5 Tonn.
Numbers	1	30	15	6	20	6	4
Monthly time of use	31.08 43.25	71 185	117 154.4	117 154.4	117 154.4	117 154.4	117 154.4
Mean of elect. consump. (Kwh) hourly	0.3	0.1	0.1	0.2	2.5	5.6	7.21
Monthly mean elec. consump. in summer (Kwh)	9.32 12.97	213 555	175.5 231.7	140.4 185.3	5850 7725	3931 5191	3374 4455
Monthly mean elec. consump. in winter (Kwh)	9.32 12.97	213 555	175.5 231.7	140.4 185.3	1351 1784	908 1199	779 1029
Monthly mean emissions in summer (Kg)	0.549 0.765	12.567 32.745	10.354 13.670	8.283 10.932	345.150 455.775	231.92 306.26	199.06 262.84
Monthly mean emissions in winter (Kg)	0.549 0.765	12.567 32.745	10.354 13.670	8.283 10.932	79.709 105.256	53.572 70.741	45.961 60.711
CFCs in each unit (Kg)	0	0	0	0.07	1.55	3.1	4.53
CFCs total (Kg)	0	0	0	0.42	31.0	18.6	18.1
Expected annual emissions (Kg)	0	0	0	0.08	6.2	3.7	3.6

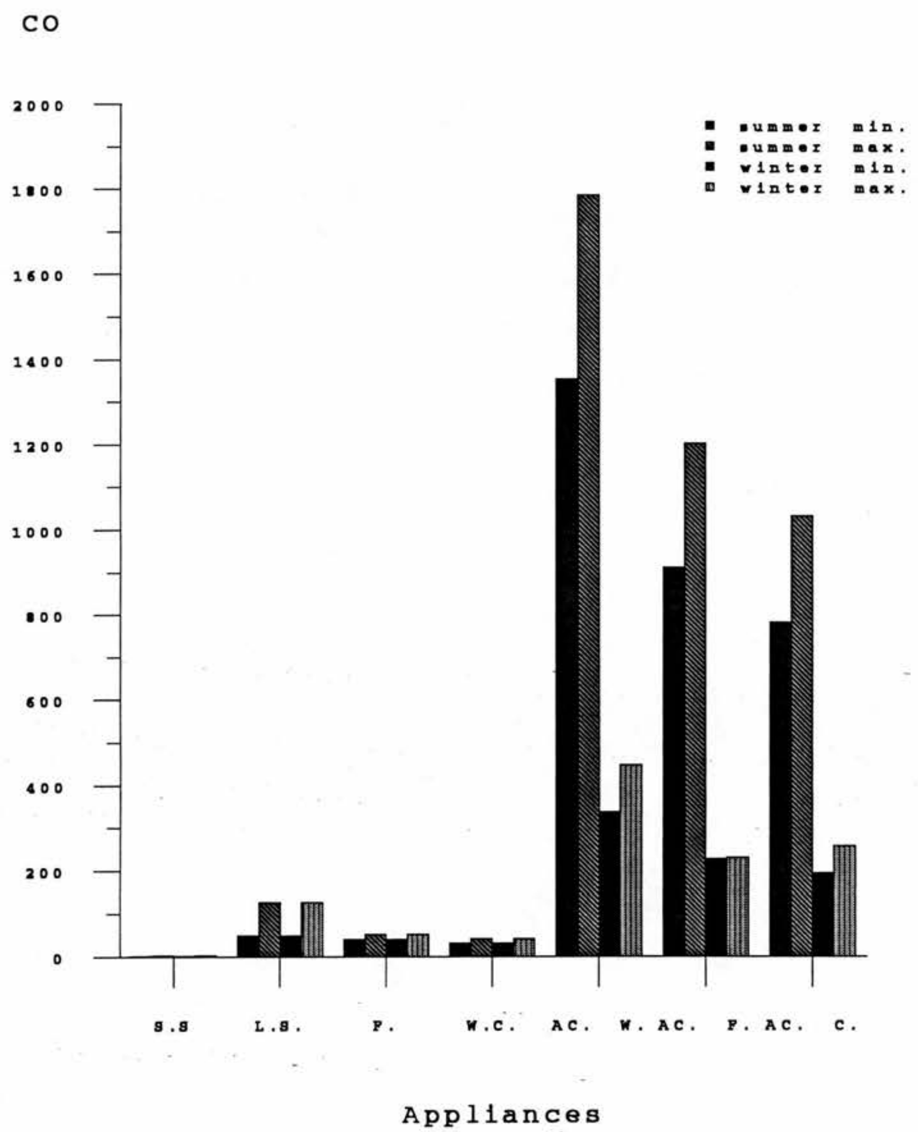

Figure 2.12 Typical mean monthly emissions of CO_2 (tonnes) related to appliances used in existing air conditioned mosque

decrease during winter.

2.4.2 Emission of CFCs

Only two appliances in air conditioned mosque are found to use refrigerants; water coolers and air conditioning systems. The amount of refrigerants in every appliance used[27,28,29] and the total have been shown in Table 2.8.

As far as the refrigerant emissions is concerned, a survey by the BRE in the UK shows that the annual loss of refrigerant ranged 10% to 20%[30]. In Saudi Arabia, the annual loss of the CFCs installed in air conditioning systems is expected to be at the higher level of 20% due to the lack of effective maintenance and engineering for this type of equipment. Based on this assumption, annual CFCs emissions from air conditioners used in mosques is estimated to range from 3.6 Kg to 6 Kg compared to 0.08 Kg from water coolers (fig. 2.13).

In this chapter, general information about Jeddah's existing air conditioned mosques has been discussed under four topics of:

1. The construction, operation and installation.
2. The physical characteristics.
3. The typical electric appliances used.
4. Estimation of CO_2 and CFCs emissions from these appliances.

The next chapter will focus on establishing the passive cooling strategy in mosques as the first proposed mean to reduce the air conditioning energy consumption, money and CO_2 and CFCs emissions levels.

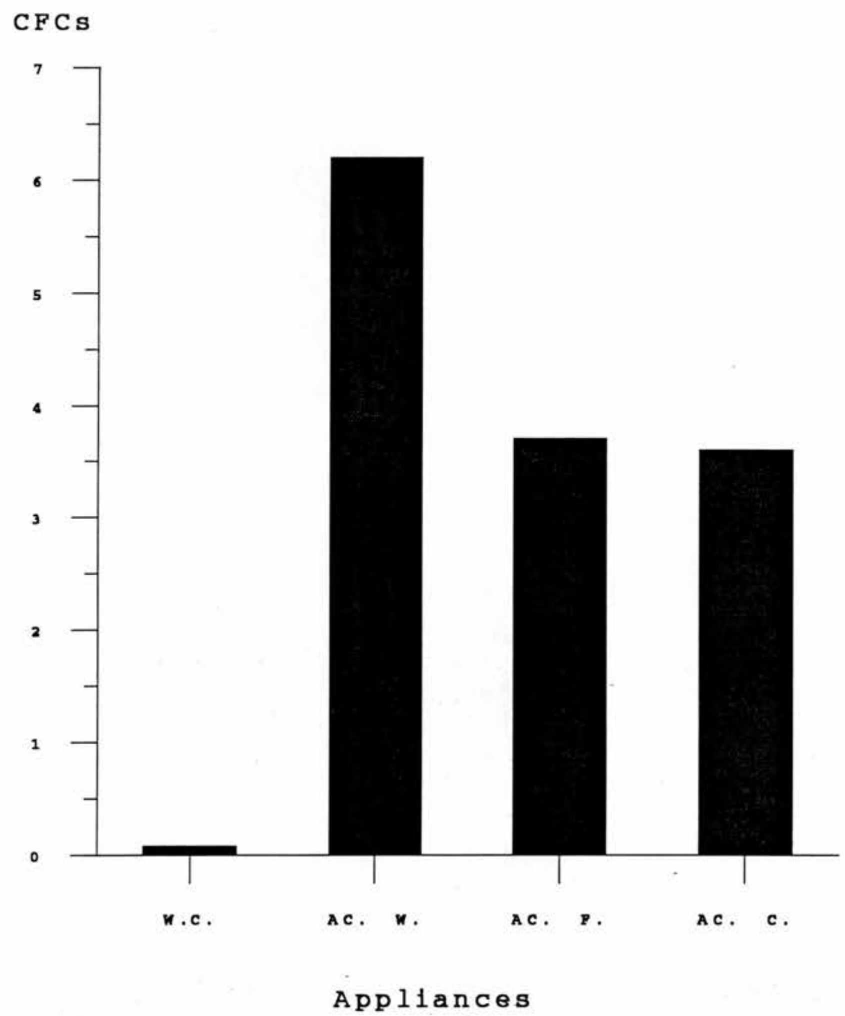

Figure 2.13 Typical annual emissions of CFCs (Kg) related to appliances used in existing air conditioned mosque

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CHAPTER THREE: CLIMATE ASSESSMENT AND COMFORT

The intention in this chapter is to establish the passive cooling strategy in mosques as the first proposed mean in reducing air conditioning energy consumption, money and CO_2 and CFCs emissions levels in existing air conditioned mosques. This will be achieved through the discussion of three main topics, namely:

(i) Time usage of Jeddah's mosques.

(ii) Climatic analysis for Jeddah's mosques.

(iii) Jeddah's mosque comfort and discomfort.

3.1 The need for cooling in Jeddah's mosques

It is essential at this stage to find out the need for cooling in Jeddah's mosque.

3.1.1 Usage times of Jeddah's mosques

In this section the main objective is to develop Jeddah's mosques' time of use isopleth.

3.1.1.1 The determination of prayer times

It is essential to give some ideas on the origin of these prayers, their numbers and times. The prayer was prescribed during the night of Isra'a (the night in which the prophet Mohammad peace be upon him was ascended to the sky) based on an authentic hadith (prophet saying) stated by Al-Bokhari in his famous book "Sahih Al-Bukhari":

Narrated Abu Dhar: Allah's Apostle peace
be upon him said" while I was at Makkah
the roof of my house was opened and Gabriel
descended....., Ibn Hazm and Anas bin Malik
said: the prophet said "Then Allah enjoined
fifty prayers on my followers,......, I went
back to Allah and requested for reduction,..
......, He said, " these are five prayers and
they are all (equal to) fifty (in reward) for
my word does not change"[1].

These daily Prayers should be offered at the stated times specified in the Holy Quran:

When ye have performed
The prayers,
Remember Allah
Standing, Sitting down,
Or lying down on your sides;
But when ye are free
From danger, set up
Regular prayers:
For such Prayers
Are enjoined on Believers
At stated Times (S.4A.103-J5)

It means: when you have finished congregational prayers. It allows you to remember Allah individually in any posture possible during the danger. But when the danger is past, the full prayers should be offered at the stated times[2].

These different times are clearly stated in the Holy Quran:

And establish regular prayers
At the two ends of the day
And the approaches of the night
For those things that are good
Remove those that are evils
That is a reminder
For the mindful (S.11A.114-J.12)

The meaning of *"the two ends of the day"* is morning and afternoon. The morning prayer is the Fajr, after the light is up but before sunrise: we thus get up betimes and begin the day with the remember of Allah and of our duty to Him. The early afternoon prayer, Duhur, is immediately afternoon: we are in midst of our daily life, and again we remember Allah. There is no disagreement among scholars regarding which prayer is meant by one of these two ends of the day. They agree that it is Fajr prayer which may be performed from dawn until a little before sunrise. There is disagreement, however, regarding the prayer which ought to be performed at the other end of the day. It is said variously that the reference is to Asr or Magrib Prayer. The meaning of *"approaches of the night"*; *zulafun*, plural of *zulfatun*, an approach, is something near at hand. As Arabic has, like the Greek, a dual number distinct from the plural, and the plural number is used here, and not the dual, it is reasonable to argue that at least three "approaches of the night" are meant. The late afternoon prayer, Asr, can be one of these three, and the evening prayer, Magrib, just after sunset, can be the second. The early night prayer, Isha'a, at supper time when the glow of sunset is disappearing, would be the third of the "approaches of the night", when we commit ourselves to Allah before sleep. These are the five canonical prayers of Islam[3].

Furthermore, the prophet peace be upon him has clarified the time ranges of each prayer and the best time, within these ranges, for the prayer to be delivered. Many hadith (prophet saying) are available in the tradition[4].

Based on the above discussion, the timing of these daily prayers is shown graphically in figure 3.1. The figure shows those prayers offered during the daytime and

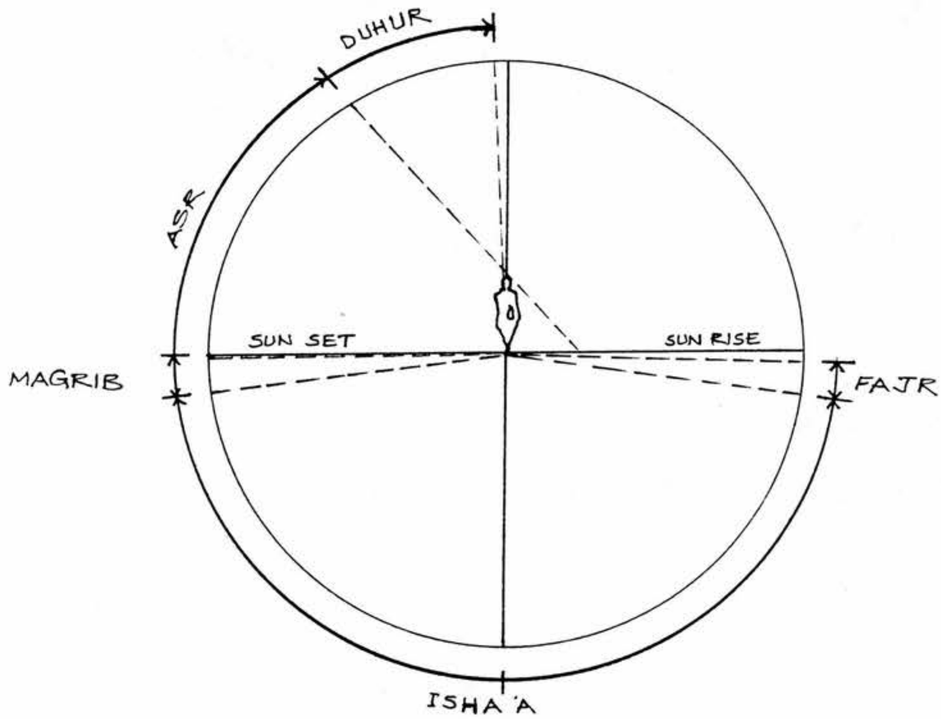


Figure 3.1 Times for daily prayers (day and night)

those practised at night. Moreover, it does indicate the time ranges of each prayer.

Based on these Quranic verses, the Ministry of Haj and Awkaf joined with other government offices and religious bodies in the Kingdom have developed time schedules for these daily prayers in hours and minutes. These time schedules are published in a calender known as "Umm Al-Qura Calender" for one year and for different cities in the Kingdom[5].

To trace the actual times for each daily prayer, four Umm al-Qura calender for four consecutive years (1990-1994) has been reviewed. The summary is presented in Table 3.1.

3.1.1.2 The usage times isopleth for Jeddah's mosques

Based on the typical times estimated for each prayer (section 2.1.7) and the times for every prayer (table 3.1), the isopleth of time usage for Jeddah's mosque is then developed (fig. 3.2).

3.1.2 Climatic analysis for Jeddah's mosques

3.1.2.1 Macro climate of Jeddah, Saudi Arabia

In order to understand how the climatic elements affect the macro climate of a particular city, it is essential to understand the general weather system that surrounds the region. There are mainly two weather systems occuring over Saudi Arabia. First, is the cyclonic one which moves from east of the Medditerranean. The other weather system

Table 3.1 Times for daily prayers, their ranges and occurrence.

Prayer	Time Min. Max.	Days
Fajr	4:11	10-14 Jan.
	5:42	15-28 Jan.
Duhur	12:08	29 Oct. - 8 Nov.
	12:39	3-20 Feb.
Asr	15:20	13 Nov. - 2 Dec.
	15:59	28 Feb. - 10 Mar.
Magrib	17:42	22 Nov. - 1 Dec.
	19:12	26 Jun. - 12 Jul.
Isha'a	19:12	22 Nov. - 1 Dec.
	20:42	26 Jun. - 12 Jul.

Source: Umm Al Qura Calender (1990-1994)

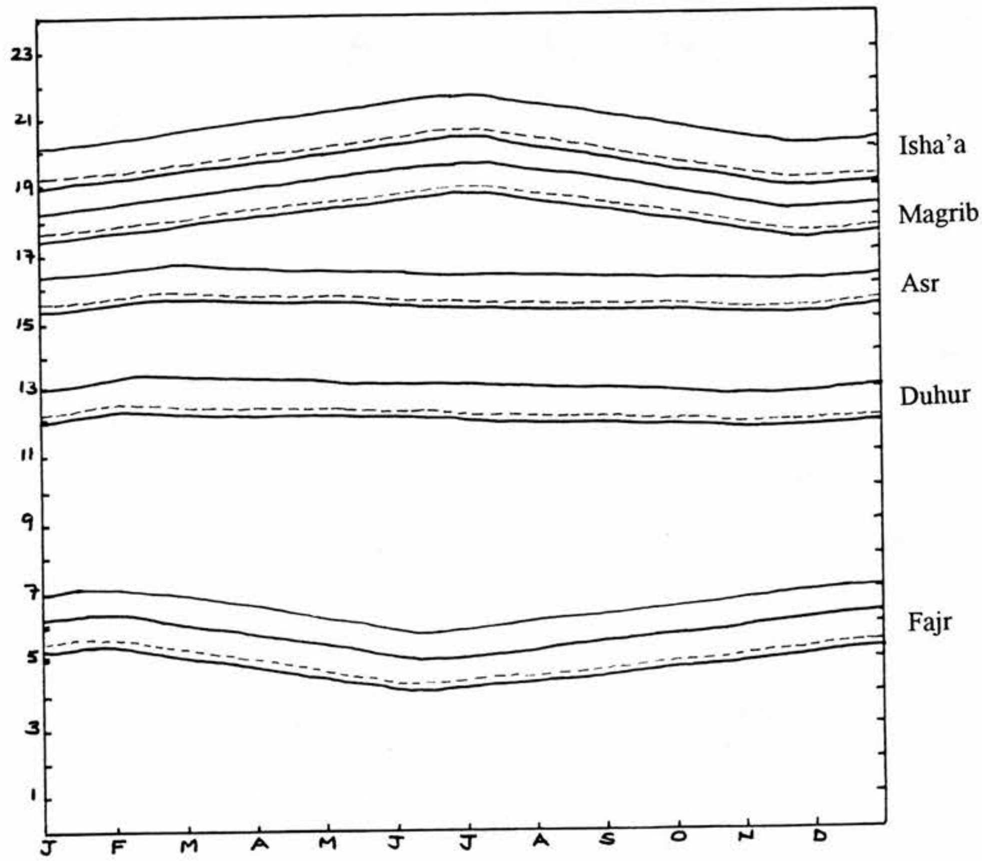


Figure 3.2 Isopleth of time usage for Jeddah's mosque

moves in a south direction along the Red Sea carrying rains particularly in the two months of March and April[6](see map 3.1).

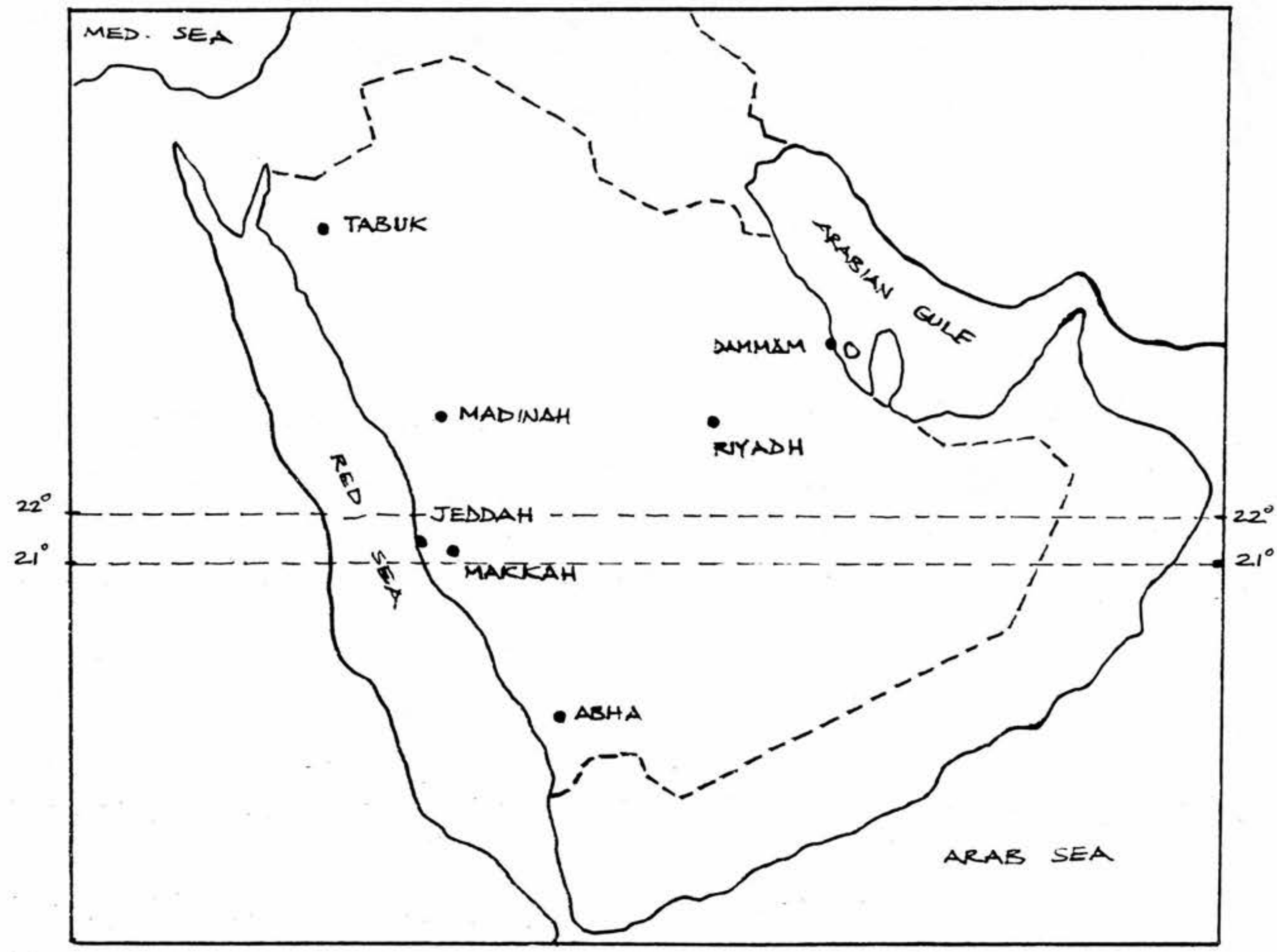
The city of Jeddah is located on 21.5 °N latitude, 39.2 °E longitude, and at about 17m above sea level. The city is situated on the Red Sea shore. As a consequence, the city's climate is influenced by two extreme climatic zones of desert and sea.

3.1.2.2 Climatic record needed and data available

Hourly data is considered detailed enough for most scientific purposes. The length of record needed for data reliability depends on the type of construction under view. A range of records of 40, 20, 13, 10 and 5 years are considered to be reliable for different types of constructions. A 13 year's record is recommended by Givoni[7].

Hour-by-hour weather data for 13 years (1970-1975 and 1977-1983) obtained from the General Directorate of Meteorology[8] were used. This data can be supplied in a form of computer diskettes or magnetic tapes. The former has been used in this research.

For the construction of Jeddah's isopleth of dry bulb temperature, relative humidity and wind speed and direction, the 13 year monthly mean was obtained by taking averages of the data over 24 hours for each month. The monthly mean values of the required variables are listed in table 3.2 . Moreover, the wind direction indicated by the wind speed isopleth was the predominant direction of each hour.



Map 3.1 City of Jeddah (21.5 °N)

Table 3.2 Summary of Jeddah climatic data during the daily prayers (1970 - 1983).

Month	Dry Bulb Temperature (°C)			Relative Humidity (%)			Wind Speed (m/s)		
	Max mean	Min mean	Mean range	Max mean	Min mean	Mean range	Max mean	Min mean	Mean range
Jan	28.5	19.6	8.9	72.1	45	27.1	11.5	3.8	7.7
Feb	29.5	19.6	9.9	72.5	45	27.5	12.4	3.8	8.6
Mar	31.5	20	11.5	70.5	45	25.5	12.4	3.8	8.6
Apr	33.4	22.8	10.6	70	46	23.4	12.4	3.6	8.8
May	34.8	24.7	10.1	70	46	24	12	3.6	8.4
Jun	36	25.7	10.3	72.5	44.3	28.2	12.2	3.6	8.6
Jul	36.7	26.8	9.9	73.5	40.9	32.6	11.8	3.6	8.2
Aug	36.7	27.8	8.9	75.5	43	32.5	12.1	3.6	8.5
Sep	35.8	27.8	8	79.6	50	29.6	11.8	3.6	8.2
Oct	34.8	24.5	10.3	79.6	44.3	35.3	11.2	2.14	9.06
Nov	33.9	22.5	11.4	77.5	44	33.5	9.9	2.14	7.76
Dec	31.2	20	11.2	73.5	44	29.5	10.6	2.14	8.46
Annual mean			10.09			29.07			8.40

Source: Weather Records in Computer Diskettes, 1970 to 1983, General Directorate of Meteorology, Western Region, Jeddah, Saudi Arabia.

The fifth parameter of interest is the solar radiation. As is typical for many countries, solar radiation data collection and compilation has not received the same attention as other meteorological parameters in Saudi Arabia. Government agencies like the Ministry of Defence, the Ministry of Agriculture and Water, Saudi Aramco and some Saudi universities have made measurements but these are seldom available on a long term basis. The construction of the solar radiation isopleth will depend on the data of Dr. Al-lyaly[9], those calculated in the College of Meteorology and Environmental Sciences at King Abdulaziz University[10] and those published in the SANCST of the "Saudi Arabian Solar Radiation Atlas" for Alsyl Alkabir near Jeddah[11].

3.1.2.3 Climatic variables

The analysis of a numerical data particularly in forms of tables of numbers is a prosaic task. Two major problems are normally associated. The first one is the difficulty in visualising the spatial and temporal behaviour of variables. The other problem is the difficulty in extracting the pattern hidden in them. These problems can be overcome if these data are transferred and presented in a different format.

The isopleth technique for describing the climate of Jeddah will be adopted in this research. It has the capabilities of not only describing the climatic data comprehensively, but also transforming numerical climate variables into visual form[12].

3.1.2.3.1 Relative humidity isopleth

The relative humidity is lowest at Duhur prayer (fig. 3.3). The mean minimum

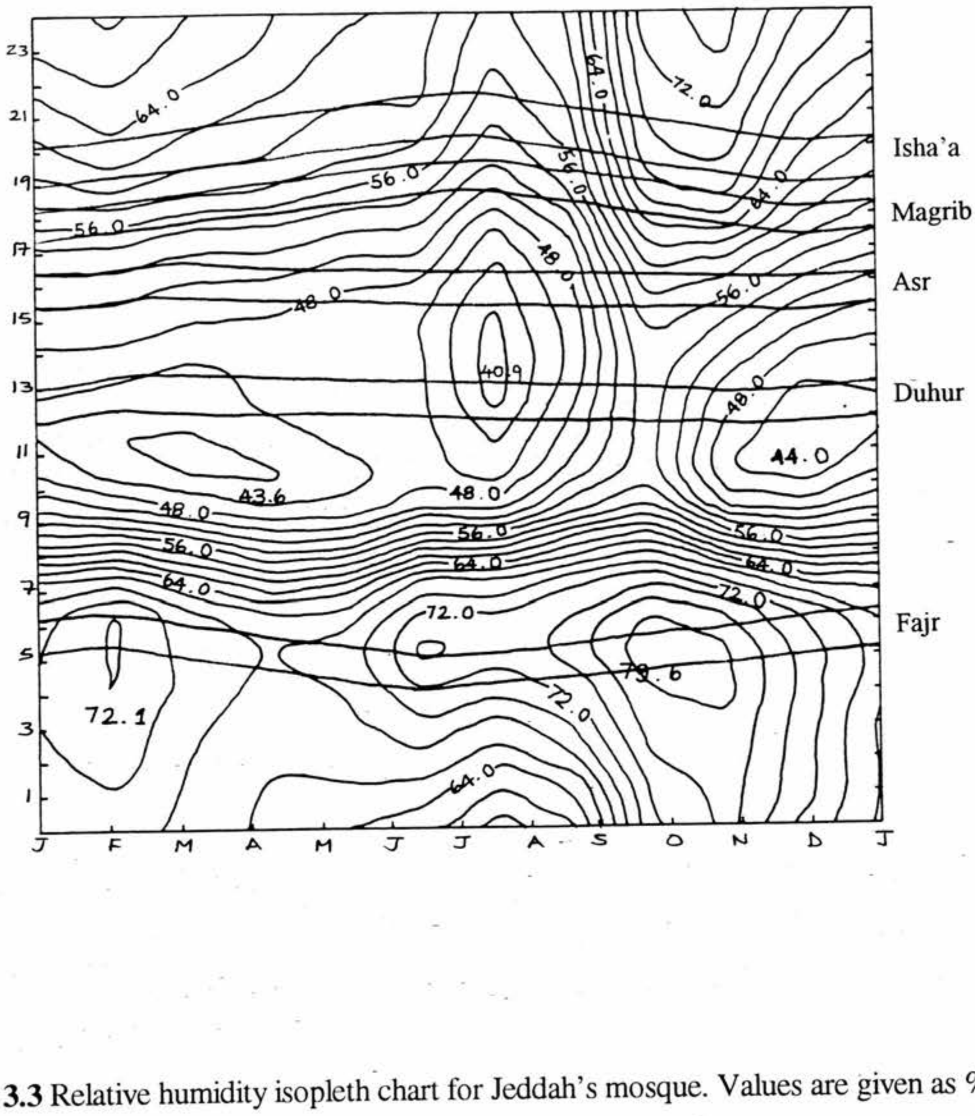


Figure 3.3 Relative humidity isopleth chart for Jeddah's mosque. Values are given as %.

relative humidity in the year is about 40.9% which occurs at Duhur prayer during July. While the mean maximum relative humidity is found to be 79.6% at Fajr prayer during the second half of September to most of October.

A difference of relative humidity for every prayer can be seen from the graph. Relative humidity ranges for every prayer is as follows:

Fajr	11.6%	Duhur	15.1%	Asr	16.8%
Magrib	18%	Isha'a	12%		

A difference of relative humidity occurs for daily prayers. Maximum difference is found to be 35.3% in October and the minimum RH is 23.4% in April.

Table 3.3 shows the maximum and minimum relative humidity mean values and their occurrences for Jeddah's daily prayers.

3.1.2.3.2 Dry bulb air temperature isopleth

The dry bulb air temperature isopleth for Jeddah's mosque (fig. 3.4) shows that the mean maximum dry bulb air temperature is 36.7°C. It occurs at Duhur prayer during the summer months of July and August. The mean minimum air temperature is found to be 19.6°C at Fajr prayer during winter times of January and the first nine days of February.

From the graph, it can be seen that for every prayer there are ranges of DBT values

Table 3.3 A Summary of relative humidity in Jeddah's mosque

Prayer	**Min. RH (%)**	**Duration**	**Max. RH (%)**	**Duration**	**Remarks**
Fajr	68	First half of April	79.6	Second half of Sept. to most of Oct.	
Duhur	40.9	all July	54	all Sept.	. For nearly 2.5 months (first of Apr. to mid. June RH = 46 to 48%. . For approx. 3 months (Jan. to end of March RH = 43 to 44%.
Asr	42-44	Mid of Jul. (mid 20 days)	56-58	Second half of Sep. to mid Oct.	. A difference of 8% RH in Sep. (50-58%).
Magrib	50	All Jul.	67.5	All Oct.	. Remains 56 to 58 % for 5.5 months (Jan. to mid Jun.). . A difference of 10% RH between the last 10 days of Aug. to the last 10 days of Sept.
Isha'a	54%	All Jul.	70-72	Last 10 days of Sep. to last 10 days of Oct.	. RH ranges between 58 to 64% for 5.5 months (Jan. to mid Jun.) . A difference of 10% RH between the last 10 days of Aug. to the last 10 days of Sept.

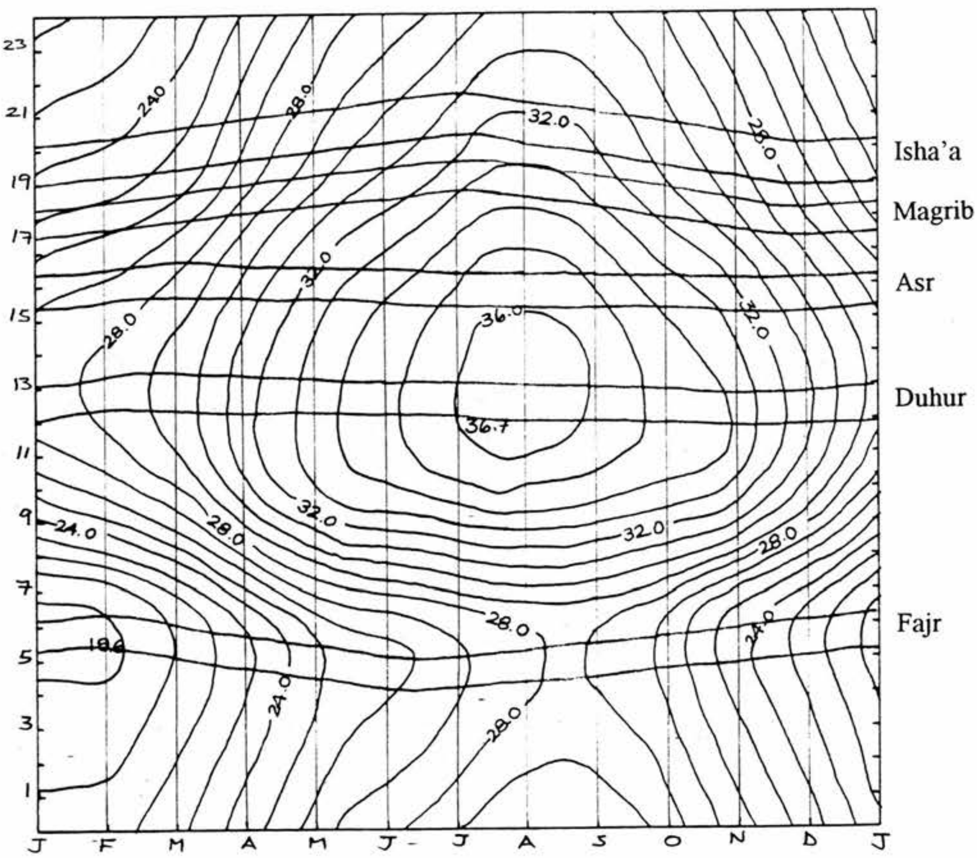


Figure 3.4 Dry bulb air temperature isopleth chart for Jeddah's mosque. Values are in °C.

estimated as follows:	Fajr	8.4°C
	Duhur	9.0°C
	Asr	9.0°C
	Magrib	8.0°C
	Isha'a	9.0°C

Between the daily prayers, there are differences of DBT. The maximum difference of 11.5°C occurs in March and the minimum difference of 8°C in September.

Table 3.4 shows in detail maximum and minimum DBT values and their occurrence within the whole year.

3.1.2.3.3 Wind speed and direction isopleth

The wind speed is lowest at Fajr prayer (fig. 3.5). The mean minimum wind speed in the year is about 2.14 m/s which occurs at Fajr prayer from the last 10 days of October to the first ten days of November. While the mean maximum wind speed found to be 12.4 m/s at Duhur prayer from the last 4 days of February to the first five days of April. The wind speed ranges values for every prayer is found to be as follow:

Fajr	2.46 m/s
Duhur	3.50 m/s
Asr	2.6 m/s
Magrib	4.0 m/s
Isha'a	4.2 m/s

Table 3.4 A summary of the dry bulb temperatures in Jeddah's mosque.

Prayer	**Min. DBT (°C)**	**Duration**	**Max. DBT (°C)**	**Duration**	**Remarks**
Fajr	19.6	Jan. and first 10 days of Feb.	28	Mid 20 Days of Aug.	DBT tends to increase towards Jul. &Aug. and decrease towards Jan. & Dec.
Duhur	27.5	First 20	36.5	Jul.& Aug.	"
Asr	26	ALL Jan.	35.5	Last 10 days of Jun. to first 10 days of Sep.	"
Magrib	25	All Jan.	33.5	First 10 days of Jul. to end of Aug.	"
Isha'a	23.7	All Jan.	32-32.5	Last 10 days of Jul.	"

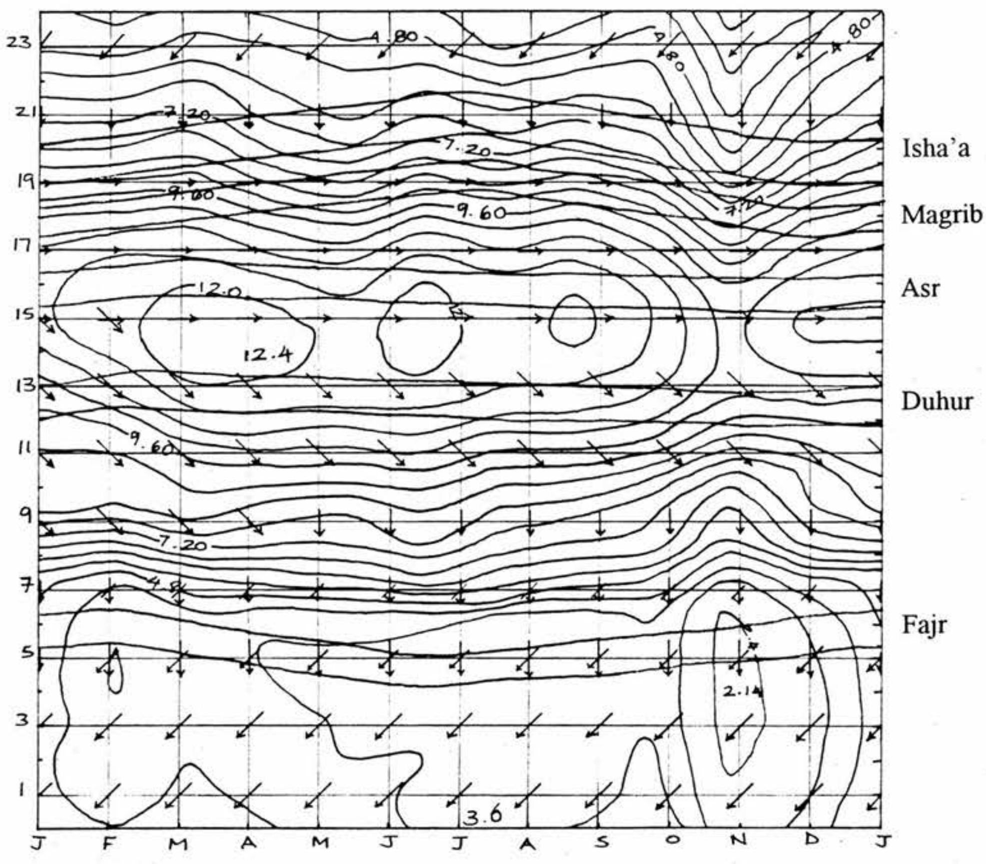


Figure 3.5 Wind speed isopleth chart with the predominant directions for Jeddah's mosque. Values are in m/s

The differences of wind speed between the daily prayers is found to be 7.7 m/s (min.) in January and 9.06 m/s (max.) in November.

Table 3.5 summarises the maximum and minimum values of wind speed, their annual presence and the predominant directions for the daily prayers in Jeddah.

During Duhur prayer, the wind blows from the north direction during the whole year. For Asr and Magrib prayers, the wind prevails from a north-west direction. Normally north and north-west winds are considered the most desirable winds, particularly in summer[13]. For Fajr and Isha'a prayers, the winds tend to blow from east and north-east throughout the year. These winds are considered the most desirable winds for summer nights .

3.1.2.3.4 Solar radiation isopleth

Unlike the other climatic parameters, solar radiation is only present during Duhur and Asr prayers (fig. 3.6). The mean maximum solar radiation intensity is 1000 W/m^2 at Duhur during April and May. The mean minimum is 200 W/m^2 at Asr prayer during the last days of December.

The solar radiation intensity annual ranges for Duhur prayer is 350 W/m^2 and for Asr is 500 W/m^2. Between the Duhur and Asr prayers, solar radiation intensity difference is found to be as much as 650 W/m^2 in January, February and March as low as 480 W/m^2 in June.

Table 3.5 A summary of the wind speeds and directions in Jeddah's mosque

Prayer	Min. WS (m/s)	Duration	Max. WS (m/s)	Duration	Remarks
Fajr	2.14	last 10 days of of Oct. to first 10 days of Nov.	4.6	. All Jan.	. Remains 3.6 m/s from first 5 days of Apr. to first 5 days Oct. . East & North East winds
Duhur	8.9	all Nov.	12.4	. Last 4 days of Feb. to to first 5 days of Apr.	. Remains 10.5 to 11.9 m/s from mid Apr. to mid Aug. . North winds
Asr	9.6	Last 10 days of Oct. to first week of Nov.	12.2	. last 10 days of Feb to to end of Mar. . Mid 20 days of Jun & Mid 15 days of Aug	. WS 12.2 m/s appears 3 times annually . North west winds
Magrib	6.6	Last 10 days of Oct. to first week of Nov.	10.6	Jan. & Feb.	. North west winds
Isha'a	4.6	7 days in Oct.	8.8	Jan. & Feb.	. North & north east winds

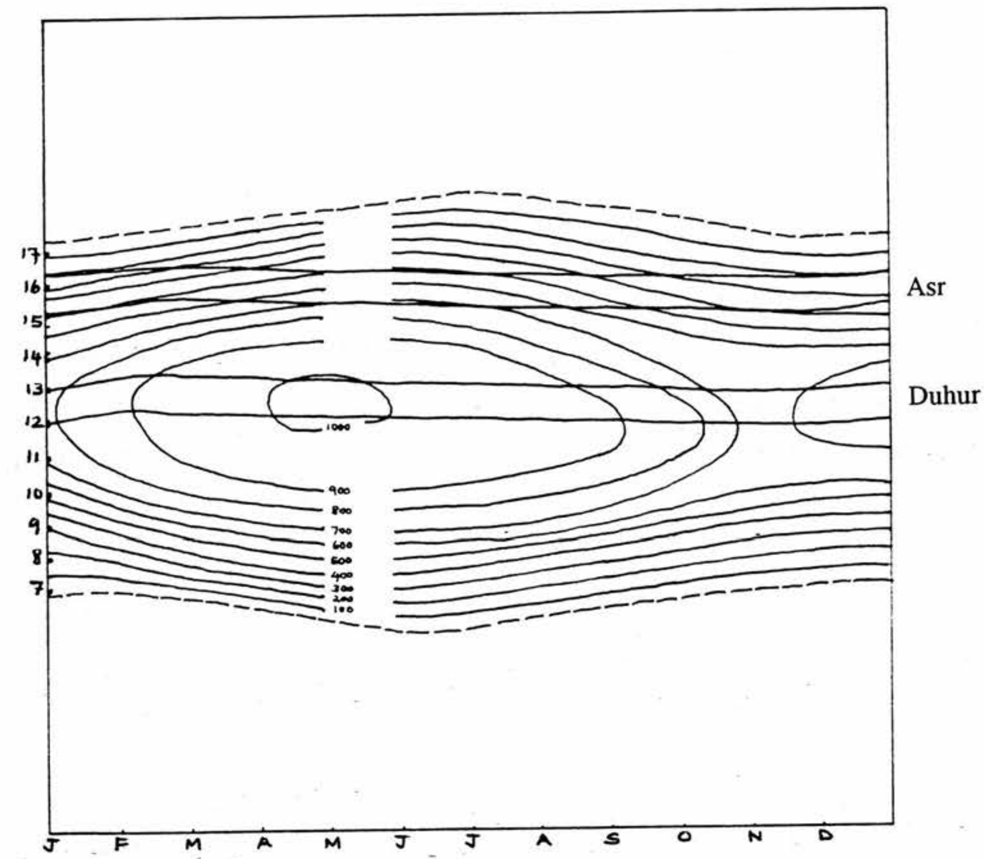


Figure 3.6 Total solar radiation incident on a horizontal plane for Jeddah's mosque. Values are in W/m^2.

Table 3.6 summarises the maximum and minimum values of solar radiation intensities and their annual presence for the daily prayers in Jeddah.

3.1.3 Jeddah's mosque comfort and discomfort

Researches on thermal comfort are numerous. Fanger, Humpherys and Nicole are pioneers in this topic. Baker and Berger are among those who specialised in thermal comfort and passive cooling. In general, the researches focus mainly on various aspects of passive cooling and human comfort in dwellings. A study of these aspects in mosque context is therefore urgently needed.

3.1.3.1 Thermal performance of the human body at praying

3.1.3.1.1 Physiological responses to thermal stress

The human body can be considered as a living building where the internal organs are the most sensitive elements with the skin acting as the envelope which should maintain comfortable conditions inside. The fat, as part of the skin composition, acts as an insulator. The skin has the ability to change its conductivity value by increasing the blood flow and discharging the heat generated in the inside to the outside environment. Blood with a considerable amount of water in its composition has the potential of storing remarkable amount of heat. There are two phenomena of blood circulation. These are known as vaso-dilation and vaso-constriction. In vaso-dilation, the blood vessels are dilated so as to allow more heated blood to pass through the skin and exchange its heat with the coolness caused by the sweat evaporation. In vaso-constriction, the opposite happens. Between the two extremes, blood flow is found to range from 0.16 to 2.2 litre/m on the skin layer[14].

Table 3.6 Solar radiation intensities for Duhur and Asr Prayers and their occurrence.

Prayer	Max.	Duration	Min.	Duration	Remarks
Duhur	1000	April & July	650	Last five days of Oct, and first 24 days of Nov.	Remains >900 from last 19 days of Feb. to first 7 days of Apr. and from 1st. of May to first 8 days of Sep.
Asr	700	May & June	200	Last days of December	no uniform Intensity

With low vapour pressure and high air velocity a greater evaporation potential is expected. The computation formulae of the maximum evaporative capacity of the air (E_{max}) as a function of air velocity and vapour pressure are several. One of these is[15]:

$$E_{max} = hc\ (P_{ssk} - P_a) \quad \text{...(3.1)}$$

where; hc The evaporative transfer coefficient in W/m mb, as hc = 13.7 V, where V is the air velocity in m/s

Pssk Saturated vapour pressure of air at skin temperature mb

Pa Vapour pressure of water in surrounding air mb

It was found that when 1 gram of water "sweat" is evaporated off the skin, more than 2000 Joules of heat are lost from the body to the atmosphere[16].

3.1.3.1.2 Variables of human comfort

Human comfort level in buildings is influenced by six variables[17]:

1. Air temperature
2. Air movement
3. Humidity
4. Mean radiant temperature
5. Clothing
6. Human activity

The first four variables are within the architect's control while the last two are totally controlled by the users of the buildings.

1. Air Temperature:

Air temperature is affected by the outdoor conditions through convection via the ventilation of the building. Convection also contributes to the air temperature inside the buildings through walls, roofs and floors. Moreover, stored heat in the building envelop affects human comfort through conduction via the air, but due to the fact that air is a very poor conductor, such an effect is considered to be marginal. According to Evans, the range of air temperature within which thermal conditions may be considered as comfortable is between 16 to 28°C[18].

2. Relative Humidity:

The relative humidity has an important role in determining the evaporative rate of the skin and its cooling efficiency (cooling by evaporation). Both extremely low and high humidity (less than 30% and more than 80%) have adverse effects on the human body, and saturated air at 100% relative humidity will prevent any evaporative cooling[19]. Olgyay has estimated the minimum level of relative humidity (rh) to be 30 - 40% for a comfortable zone and 50% is considered to be the optimum and 70% as the maximum desirable[20]. However, it should be noted that the effect of humidity on the evaporative capacity is interrelated with the effect of air velocity. An increase in air velocity may offset the effect of a high humidity and still raises the evaporative capacity of the body.

3. Air Velocity:

Air velocity affects the human body by enhancing evaporation of moisture from the skin and increases its heat loss by forced convection. The heat exchange to and from the body under the air movement effect depends mainly on air temperature and relative humidity. At high air temperature there is an optimum value of air velocity at which the motion produces the highest cooling[21]. Reducing it below this level causes discomfort and heating due to the reduction of the sweating efficiency, and increasing it beyond this level results in heating by convection. This optimum level is not fixed and depends on the combined effect of temperature, humidity, metabolic level and clothing. However, for indoor comfort conditions the air movement is restricted by the human sensation towards the various velocity levels as follows:

up to 0.25 m/s	Unnoticed
0.25 - 0.50	Pleasant
0.50 - 1.00	Awareness of air movement
1.00 - 1.50	Annoying, Draughty

In certain climatic conditions these values may not match the thermal sensation of the body. In cold climates, an air velocity of 0.25 m/s may not be exceeded. However, in hot climates high velocities are necessary to achieve comfort.

4. Mean Radiant Temperature:

The mean radiant temperature or MRT within a room is the sum of the heat radiated from all the internal surfaces to the centre expressed on a temperature scale. With the assumption of the same emissivity value for all related surfaces, it can be calculated as follows[22]:

MRT = (A1.t1 + A2.t2 +.....)/(A1 + A2+....) ....(3.2)

where;

A1,A2 areas involved in total effect of MRT in m.

t1,t2 corresponding temperatures of the different surfaces in °C

MRT and air temperature are supposed to be in a close range[23]. In a hot climate, intense solar radiation, and a poorly insulated building help to heat the building envelope. This heated envelope will radiate this heat to the indoor.

5. Clothing:

Thermal comfort of the human body is also affected by the level of clothing. Clothing can be viewed as an insulation barrier in a cold weather while serving opposite purposes in hot-humid weather. Clothing might increase the vapour pressure around the body, thus preventing the sweat evaporation from taking place. Or it might reduce heat gain via radiation particularly when a person is at rest. Clothing was found to increase the sweat rate for hard working men and reduce the sweat rate of resting men compared with unclothed men[24].

The clothing factor Clo is a numerical measure of the effect of clothing. It can be quantitatively defined as an averaged thermal resistance of 0.155 m °C/W[25]. One Clo unit is the thermal insulation needed to keep a sedentary person comfortable at 21°C. Table 3.7 gives Clo values for some clothing outfits.

6. Activity:

The limits of human comfort levels are also affected by the metabolic and physical heat production of the human body. In the case of metabolic heat production, the influence exercises in two ways. It has been found that during sleeping or resting in a comfortable temperature, the human body generates the least metabolic heat. Under low temperature, the body tends to increase its metabolic rates in relation to the decrease in temperature-which might reach a level 2-3 times normal at severe cold stress[26]. The temperature at which the body generates the least metabolic heat is known as the critical temperature. This is found to be 25.2°C[27]. For temperatures above this, an increase of metabolic rate by up to 30% can be expected under severe heat condition[28]. This is primarily due to chemical reaction and pulse rate. When a person is working, his body will generate more heat and consequently the surrounding comfort temperature should be lowered. Usually the heat generated by the body is measured according to the oxygen consumption of the body. Table 3.8 lists average values of metabolic rates for adult man practising different activities.

3.1.3.2 The development of mosque comfortable conditions

Field studies carried out throughout the world have shown a close relationship between the preferred indoor temperatures and the mean outdoor temperature.

Table 3.7 Insulation values of some clothing outfits

Clothing	Clo
Nude	0.0
Light sleeves dress, cotton underwear	0.2
Light trousers, short sleeve shirt	0.5
Warm, long sleeve dress, full length slip	0.7
Light trousers, vest, long sleeve shirt	0.7
Light trousers, vest, long sleeve shirt, jacket	0.9
Heavy three piece suit, long underwear	1.5

Source: McIntyre, D. (1980). Indoor Climate. London: Applied Science Publications Limited, p. 47.

Table 3.8 Metabolic rates for young adult males

Activity	Metabolic level (W/m)
Sleeping	41
Reclining sitting	47
Sitting	58
Standing relaxed	70
Walking, level at 3.2 km/h	116
Walking, level at 4.8 km/h	151
Walking, level at 6.4 km/h	221
Walking upward 15 slope at 3.2 km/h	267
House cleaning	116-198
Sawing by hand	232-280
Heavy machine work	204-262

Source: Markus and Morris (1980). Building, Climate and Energy. London: Pitman International Text, p. 43.

between the preferred indoor temperatures and the mean outdoor temperature.

Higher temperatures are acceptable in spaces with transitory occupancy. Normally, internal temperature swings are limited to about 2-4°C to take into account economic considerations for the building structure and plant provisions. But higher temperature swings are permissible in spaces with intermittent occupancy.

The comfortable internal temperature for a mosque can be estimated by using the equation[29]:

$$O = 37 - M\,[0.05 + 0.7\,(Rc + 0.113)]$$

where;

O	is the comfortable internal temperature in °C
Rc	is the clothing resistance = 0.047 m °C/W
M	is the metabolic rate of praying = 60 W/m^2

The acceptable temperature would be = 27.3°C

3.1.3.3 Jeddah's mosque comfort and discomfort

The influence of the climatic variables of dry bulb air temperature, relative humidity, air speed and radiation on the thermal comfort sensation of people has been investigated by many scientists such as Givoni[30], Olgyay[31] and Webb[32]. Evans[33] has summarized their works and presented scales for comfort temperature ranges against relative humidities for three conditions (table 3.9). These three different scales are as follows:

1. The upper scale: gives the dry bulb air temperature range against relative humidity at air speed 1.0 m/s.
2. The central comfort zone: the subject wears summer clothes during the day, uses a single sheet at night and experiences an air speed of 0.1 m/s.
3. The lower scale: gives comfortable temperature ranges for subject who wears warm clothes during the day and uses thick bedding at night.

Evans[34] argues that the temperature ranges indicated in table 3.9 are average ranges and do not imply that everyone will feel comfortable when temperatures are within suitable range. He believes that age, sex, diet, the physical body shape and state of health and acclimatisation will affect the sensation of comfort and that the comfort zones can only signify the conditions under which about 70% of people will feel comfortable[35].

Based on the mosque comfort internal temperature previously estimated, (27.3°C), it can be seen clearly that this value is within Evan's central comfort condition. Consequently, Evans scale is applicable in the mosque domain[36] and therefore is adopted in the investigation of comfort and discomfort in mosques. Appropriate comfort temperature ranges can be obtained for 12 months of the year by comparing the mean monthly maximum and minimum dry bulb air temperatures and relative humidity as related to mosque times use (table 3.2) against the temperature ranges given by Evans' scales (table 3.9). The comfort temperature ranges obtained this way for Jeddah's mosque are shown in table 3.10. By applying these ranges to the dry bulb air temperature isopleth the comfort

Table 3.9 Comfort temperature ranges

Scale	Conditions	Humidity (%)	Day temp °C	Night temp °C
A	Upper range of comfort with 1 m/s movement	0-30	32.5-29.5	29.5-27.5
		30-50	30.5-28.5	29.0-26.5
		50-70	29.5-27.5	28.5-26.0
		70-100	29.0-26.0	28.0-25.5
B	Range of comfort with light summer clothes or 1 Blanket at night	0-30	30.0-22.5	27.5-20.0
		30-50	28.5-22.5	26.5-20.0
		50-70	27.5-22.5	26.0-20.0
		70-100	27.0-22.5	25.5-20.0
C	Lower range of comfort with normal or warm clothes and thick bedding at night	0-30	22.5-18.0	20.0-16.0
		30-50	22.5-18.0	20.0-16.0
		50-70	22.5-18.0	20.0-16.0
		70-100	22.5-18.0	20.0-16.0

Source: Evans, M. (1980). Housing, Climate and Comfort. London ; The Architectural Press, p. 23.

Table 3.10 Day and night-time comfort temperature ranges for daily prayers in Jeddah's mosques obtained by Evans method

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
DAY	28.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5
	22.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5
NIGHT	20.0	20.0	20.0	26.0	26.0	28.0	28.0	28.0	28.0	25.5	25.5	20.0
	16.0	16.0	16.0	20.0	20.0	25.5	25.5	25.5	25.5	20.0	20.0	16.0

zone chart for Jeddah's mosque is developed (fig. 3.7). Zones which meet Evans's middle scale criteria are the comfort zones, and zones which satisfy Evans's upper and lower scale criteria are modified comfort zones. Zones which do not meet the criteria of any of these scales are classed as discomfort zones.

From the comfort chart (fig. 3.7), it is interesting to note that in Jeddah's mosque approximately 22.68% of the prayers offered annually (414 out of 1825) falls within comfort zone. Nearly 22% (402) is in modified comfort zone. 55% (1009) of the prayers are beyond these limits, and they are within discomfort zones (table 3.11). These prayers will be named as "discomfort prayers" in this research. The distribution of these discomfort prayers are as follows:

20 Fajr prayers in August.

265 Duhur prayers from mid March to the first 7 days of December.

238 Asr prayers from the beginning of April to the last 28 days of November.

262 Magrib prayers from the last eight days of March to mid December.

224 224 Isha'a prayers from the first 10 days of April to the last 8 days of November.

3.1.4 The need for cooling

A further analysis is needed to define the nature and the extent of this discomfort in mosques with the use of Evans' limits[37] of comfort and discomfort for day and night conditions (table 3.12). By comparing dry bulb air temperatures and corresponding relative

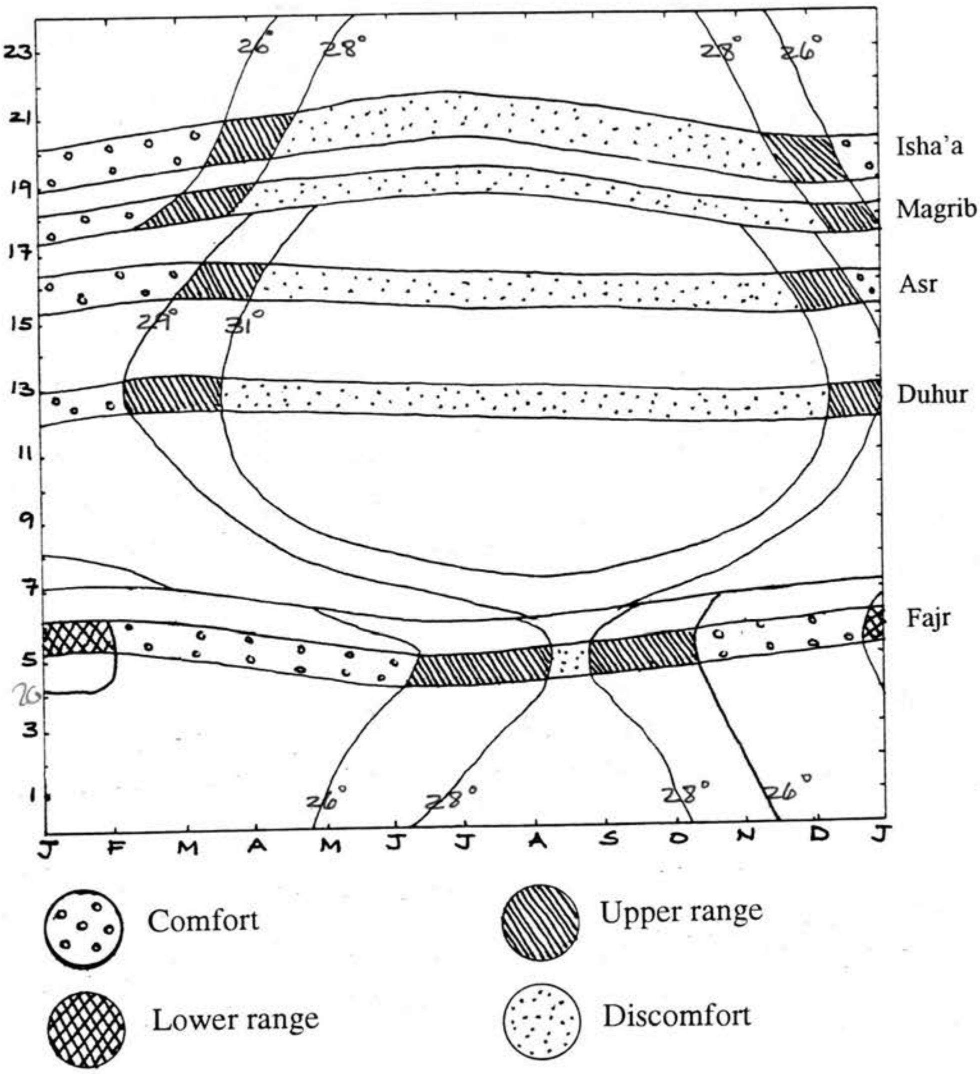


Figure 3.7 Comfort chart for Jeddah's mosque

Table 3.11 Annual distribution of the prayers numbers as related to comfort and discomfort conditions

Prayer		Comfort		Discom-fort	Total
	Lower	Normal	Upper		
Fajr	37	180	128	20	365
Duhur	-	38	62	265	365
Asr	-	70	57	238	365
Magrib	-	40	63	262	365
Isha'a	-	86	55	224	365
Total	37	414	365	1009	1825
%		44.71%		55.28%	

Table 3.12 Temperature and humidity limits for different forms of discomfort.

Condition	Average daily temp. for the month (°C) Max.	Min.		Average daily humidity for the month (%) Max.	Min.		Diurnal range (°C)
1. High temp. and high humidity	over 27.0	-	and	-	over 70%		-
	or over 27.5	-	and	-	50-70%	and	10 °C or less
2. High temp. and high diurnal range	over 32.5	-	and	-	0-30%		-
	or over 30.5	-	and	-	30-50%		-
	or over 29.5	-	and	-	50-70%	and	>10 °C
3. Excessive discomfort	over 30.0	-	and	-	0-30%		-
	or over 37.0	-	and	-	30-50%		-
	or over 35.5	-	and	-	50-70%	and	>10 °C
	or over 32.0	-	and	-	over 70%	and	10 °C or less
4. Day and night comfort but	below 32.5	above 10	and	-	0-30%	and	>10 °C
	or below 30.5	above 10	and	-	30-50%	and	>10 °C
	or below 29.5	above 10	and	-	50-70%	and	>10 °C
	or below 29.0	above 10	and	-	over 70%	and	>10 °C
5. Day Comfort	All conditions not included in 1,2,3,4 or 6						
6. Low day temperatures	15-18 (fresh)	-		-	-		-
	10-15 (cool)	-		-	-		-
	below 10(cold)	-		-	-		-
7. High temp. and high humidity by night	-	above 27.5	and	above 70%	-		-
	or -	above 26.0	and	50-70%	-	and	10 °C or less
8. High temp. and low humidity by night	-	above 27.5	and	0-30%	-		-
	or -	above 26.5	and	30-50%	-		-
	or -	above 26.0	and	70-70%	-	and	>10 °C
9. Low night temp.	-	below 10		-	-		-

Source: M. Evans, op. cit., p. 29.

humidity shown in figures (3.3) and (3.4) the comfort and discomfort analysis is further elaborated (fig 3.8).

It can be seen from fig (3.8) that for 50.2% of the total discomfort prayers, the discomfort is due to high temperature and high relative humidity by night. For the remaining 49.8% the discomfort is due to high temperature by day.

It is therefore safe enough to conclude that discomfort in mosque is primarily caused by high temperature or in other word over heating. As a consequence, cooling is needed in mosque buildings.

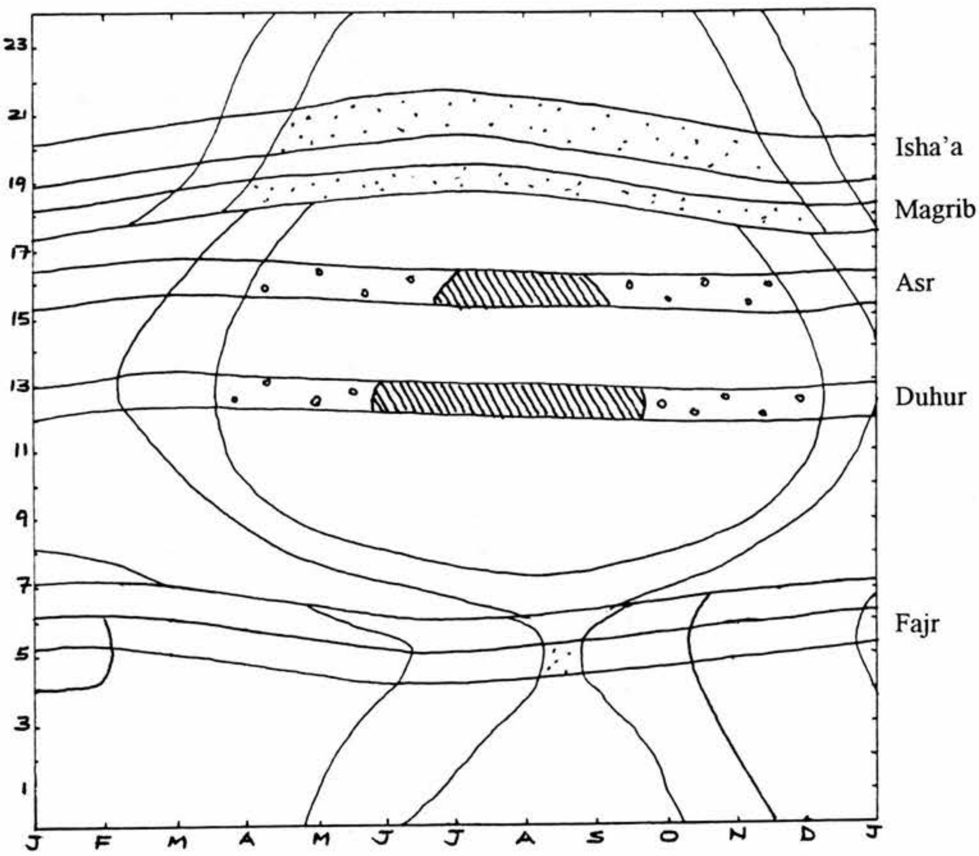
3.2 Cooling strategies in Jeddah's mosques

It is important at this stage to define what are the cooling strategies needed in mosques.

Based on Evans[38] conditions for the use of different cooling tools to reduce discomfort or maintain comfort (table 3.13), the cooling strategies needed in mosques has been developed in table (3.14). Moreover, the use of these strategy for every prayer has been shown (fig. 3.9). Two main strategies has been defined are as follows:

1. Passive cooling strategy related to air movement

    a. Under high temperature and high humidity conditions, moist or damp



Excessive discomfort due to high temperature by day

Discomfort due to relatively high day temperatures

Discomfort due to high relative humidity and temperatures by night

Figure 3.8 Discomfort analysis for Jeddah's mosque.

Table 3.13 Conditions under which mechanical cooling may be necessary to achieve comfort.

Form of cooling	Conditions		Notes
	Temp. (°C)	RH (%)	
Evaporative cooling	35-37	below 35%	Below 35 °C thermal capacity will reduce maximum temperatures
	37-40	below 25%	
Air cooling	35-37.5	30-60%	Humidification required when relative humidity is below 10-15%
	37.5-40	20-50%	
	40-42.5	0-45%	
	42.5-45	0-40%	
Air cooling and de-humidification	31-33	above 85%	below 31 °C air movement can be used
	33-35	above 70%	
	35-37.5	above 60%	
	37.5-40	above 50%	
	40-45	above 40%	

Source:M. Evans, op. cit., p. 28.

Table 3.14 Summary of the cooling strategies and the prayers involved.

Prayer	Temp. (°C)	RH (%)	Tools for cooling	Total no. of prayers
Fajr	>28-<29	72-76	Air movement	20
Duhur	>35	40.9-54	Mechanical cooling	104
	>31-<35	44-55	Thermal mass	161
Asr	>35-35.8	42-50	Mechanical cooling	75
	>31-<35	>44-58	Thermal mass	163
Magrib	>28-<31	54.5-<70	Air Movement	160
	>31-33	50-76	Thermal mass	102
Isha'a	>28-<31	58-71	Air movement	71
	>31-33	54-68	Thermal Mass	153

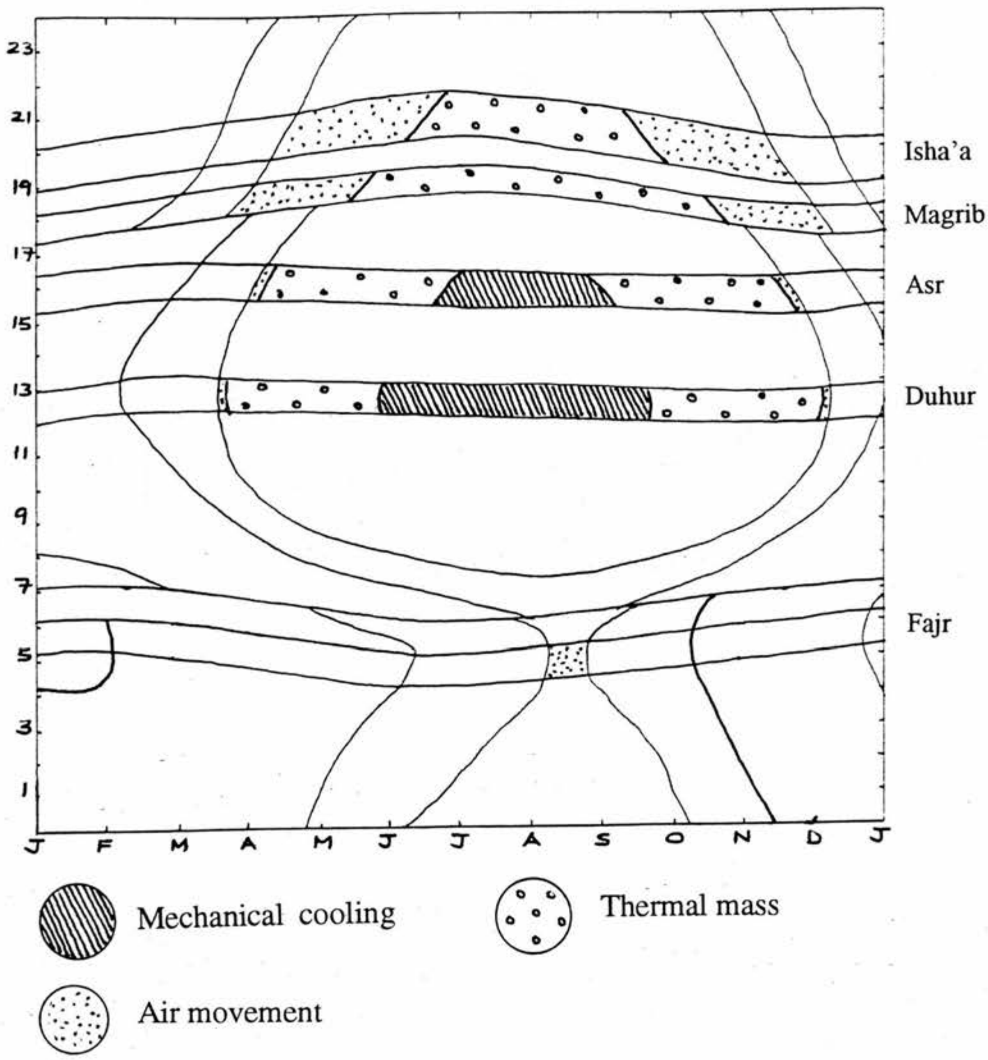


Figure 3.9 Cooling Strategies within discomfort zones for daily prayers

skin is a particular problem and air movement is required to increase the evaporation of sweat. This will dry the skin and improve the efficiency of evaporative cooling of sweat as well as increasing heat loss from the skin by convection[39].

b. The ranges are found to be >28°C to below 31°C at night and >30.5 to below 31°C in daytime.

c. Air movement is needed in the following prayers:

   i. 20 Fajr prayers in August.

   ii. 10 Duhur prayers in 5 days before end March and first 5 days on December.

   iii. 10 Asr prayers in the first 5 days of April and last 5 days of November.

   iv. 160 Magrib prayers from the last ten days of March to the first 20 days of May and from the first 24 days of October to the first two days of December.

   v. 71 Isha'a prayers from the last 20 days of April to mid June and from the first of October the first 20 days of November.

2. Passive cooling strategy related to thermal mass

   a. There are some uncomfortably hot conditions where air movement is not the most appropriate method of achieving comfort. These conditions occur when the skin is dry, moisture on the skin can evaporate freely without increased air movement, and air movement only affects heat exchange by convection. As the temperature increases closer to the skin temperature of 35°C the convection heat loss is reduced and as the temperature increases above the skin temperature increased air movement will cause heat gain and increased thermal stress, therefore thermal capacity is needed[40].

b. The ranges are found to be >31 and below 35°C in daytime and >31 to 33°C at night.

c. Thermal mass is found to be appropriate in the following prayers:

    i. 151 Duhur prayers from last 3 days of March to the end of May and from the first 10 days of September to the end of November.

    ii. 153 Asr prayers from last 25 days of April to the first 20 days of June and from first of September to last 25 days of November.

    iii. 102 Magrib prayers from the last 11 days of May to the first 7 days of October.

    iv. 153 Isha'a prayers from the last 15 days of June to the end of September.

3. Active or mechanical air cooling strategy:

    a. When temperature is so hot that neither air movement nor thermal capacity can be used to achieve comfort mechanical aids such as humidifiers, air conditioners and air coolers may have to be used[41].

    b. The range is found to be >35°C and relative humidity 40-54%.

c. Mechanical air cooling systems are needed in 104 Duhur prayers from First of June to the last days of September. And 75 Asr Prayers from last 10 days of June till the end of August.

In conclusion, the proposed passive cooling strategy is capable of restoring comfort inside the mosque for substantial number of prayers while the active cooling strategy is only needed in less number of prayers.

In this chapter, the need for cooling and the proposed cooling strategy in Jeddah's mosques have been discussed. This has been achieved through the discussion of three main topics of;

(i) Time usage of Jeddah's mosque.

(ii) Climatic analysis for Jeddah's mosque.

(iii) Jeddah's mosque comfort and discomfort.

The strategy involves the use of air movement and thermal mass during substantial number of prayers. In the following chapter the discussion will be primarily related to the definition of the various passive cooling improvement measures as the second proposed mean in reducing air conditioning energy consumption, money, and CO_2 and CFCs emissions levels in existing air conditioned mosques.

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CHAPTER FOUR: PASSIVE AND ACTIVE COOLING SYSTEMS IN EXISTING AIR CONDITIONED MOSQUES

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CHAPTER FOUR: PASSIVE AND ACTIVE COOLING SYSTEMS IN EXISTING AIR CONDITIONED MOSQUES

In the previous chapter, the proposed passive cooling strategy as a means to reduce air conditioning energy consumption, money, and CO_2 and CFCs emission levels in existing air conditioned mosques has been defined. The strategy involves the use of air movement and thermal mass during a substantial number of prayers. In this part, the intention is to define the second proposed means of passive cooling improvement measures. The definition of these improvement measures requires the study of the following subjects:

a. Passive cooling systems in existing mosques.

b. The definition of passive cooling systems which demand improvement.

c. The detailed study of these passive cooling systems defined.

Each of the above topics has been discussed in a separate chapter. In this chapter, the objective is to discuss the different passive and active cooling systems used in existing air conditioned mosques in:

a. Jeddah, under two categories;

  i. Those are adopted in all mosques.

  ii. Those which are used in few mosques.

b. Other systems used in mosques in other parts of the world under similar climatic conditions.

4.1 Cooling methods

Principally, there are two cooling methods for a building[1] (see fig. 4.1). The first one, is to reduce heat gains through the reduction of (a) solar radiation

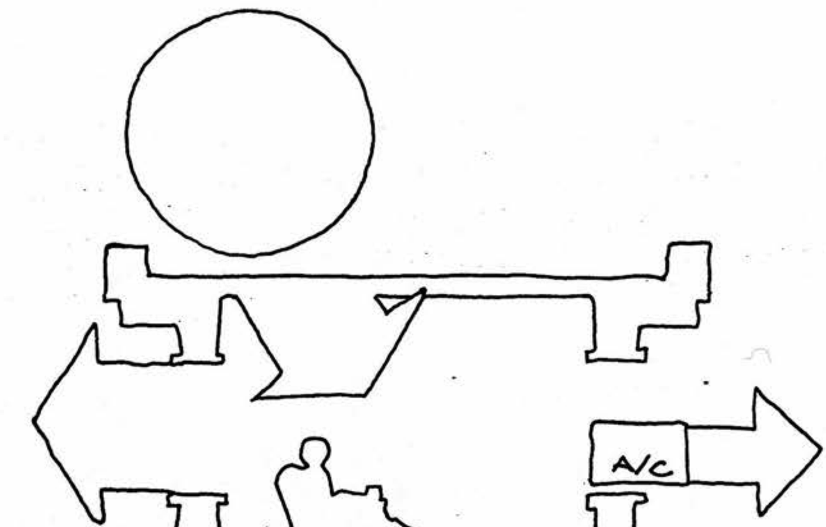

Figure 4.1 Cooling methods in buildings

interception and (b) absorption and inward transmission by the building envelopes. The other one, is to remove heat developed inside the building, requiring a lower temperature region in which to discharge the heat, a heat sink. Two types of heat sinks are available; natural and artificial. The natural are air, sky, water, and earth. The artificial one is the air conditioner. Consequently, based on the cooling methods specified, these methods are applied in a form of cooling systems. These cooling systems are classified in this study into two groups;

a. Mechanical cooling systems; which remove heat through the provision of artificial heat sinks.

b. Non-mechanical cooling systems, which reduce heat gains (through solar radiation interception and absorption and inward transmission by the building envelopes) and remove heat with the use of natural heat sinks. In this research, these systems will be called passive cooling systems, based on the fact that both measures of minimising heat and maximising heat loss by removing heat from buildings once it is inside are addressed[2,3]. Both systems are currently used in existing mosques and will be discussed in detail.

4.2 Mechanical cooling systems

The principal means of achieving thermal comfort at present in existing mosques are through air conditioners. Air conditioning serves several purposes other than just cooling. Cooling and humidity control are often the basic functions of air conditioning systems. In addition the system may also provide other functions such as ventilation and heating.

The principal mechanical cooling method in practical use in Jeddah's existing air conditioned mosques is Vapour Compression Refrigeration. This method involves transferring the heat from one location to another, utilising the physical thermal properties of liquid-gas transference of certain fluids such as chloroform and ammonia. The method involves the provision of cooling and the delivering of cooling to the occupied space.

The vapour-compression refrigeration cycle is illustrated in figure 4.2. Its basic components are the following[4]:

(a) Evaporator; transfer heat from the cooled space to the refrigerant by evaporating the liquid refrigerant to a gaseous state.

(b) Compressor; compress the refrigerant gas to make it much warmer than the surrounding air. This part of the system is the one that consumes most of the energy required by the system.

(c) Condenser; transfers the heat to the outside air through refrigerant gas by condensing it into liquid which is then used in the next cycle.

(d) Expansion valve; relieves the pressure built-up by the compressor, consequently, reducing the refrigerant temperature even further to enable it to evaporate again and transfer the resulted reductions in temperature through the evaporator.

Three types of air conditioning systems using the mechanical cooling method of vapour compression refrigeration are commonly used in Jeddah’s existing mosques. These are window type air-conditioners, split unit air-conditioning and central air conditioning.

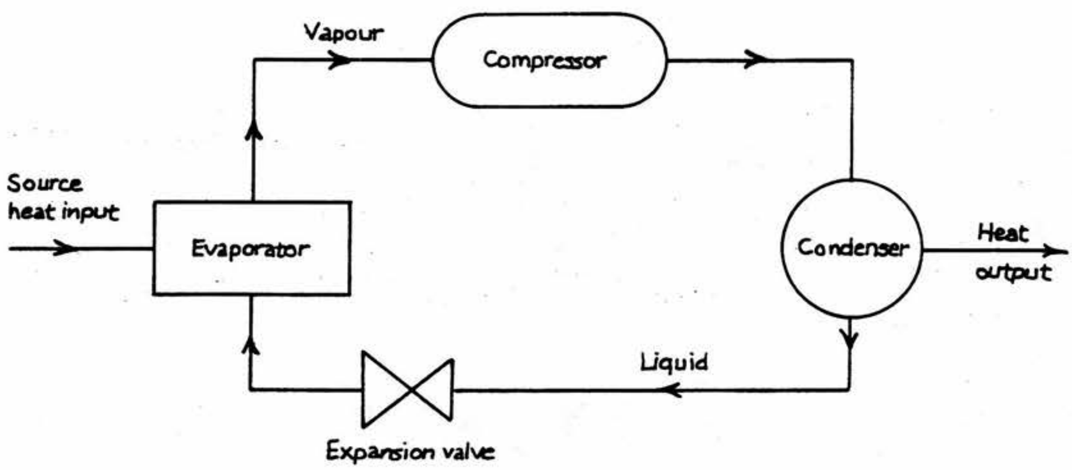

Figure 4.2 Vapour-compression refrigeration cycle.

Source: Osbourn 1985, 166.

The window type air-conditioner is a compact refrigerating machine placed across the wall of the prayer hall, where the outlet is inside the room for supplying cold air and the inlet is kept outside the room to exhaust the heat produced by the system. It is commonly used in small mosques with a cooling capacities ranges between 18000-24000 Btu and has the lowest installation cost among the other two types. 15 to 20 units of 18000 Btu cooling capacity are commonly installed when used in large mosques.

The split unit air-conditioning is the most popular type used in the majority of existing mosques. It consists of a condensing unit placed outside the room for noise and heat reasons and a blower-coil unit placed inside the room to supply the room with cool air. These two split units are connected together with a liquid line and a suction line; the former for supplying the cooler air and the latter for sucking out the returned air. The system is considered to be more efficient in cooling the space and consumes less energy. Moreover, it does not exhaust heat at the same place of cooling because the condensation unit is away from the room either in the roof or on the ground level. The system is less noisy during operation, because the indoor unit operates with whisper-quiet efficiency and employs a noiseless fan. Six units of 50000 Btu are typically used in existing mosques.

The central air-conditioning cooling system is a package type unit large in size and has high cooling efficiency. The whole unit is kept away from the prayer hall either on the roof or on the ground, providing cool air to the hall with the use of ducts. The system is high in cost and has low level of noise. Up to four units of 5 ton (60000 Btu) cooling capacity is commonly installed. The system is widely used in existing mosques. The three systems and their locations are illustrated in figure 4.3.

4.3 Passive cooling systems in mosques

The passive cooling systems used in existing air conditioned mosques can be divided into two groups:

1. Those related to heat gain reduction strategy.
2. Those related to heat removal strategy.

4.3.1 Passive cooling systems related to solar heat gain reduction strategy

These passive cooling systems are of two types:

1. Those related to solar radiation interception;
   a. For shading.
   b. For direction and shape.
2. Those related to absorption and inward transmission;
   a. For reflective and emission properties.
   b. For insulation.
   c. For thermal capacity.
   b. For glazing.

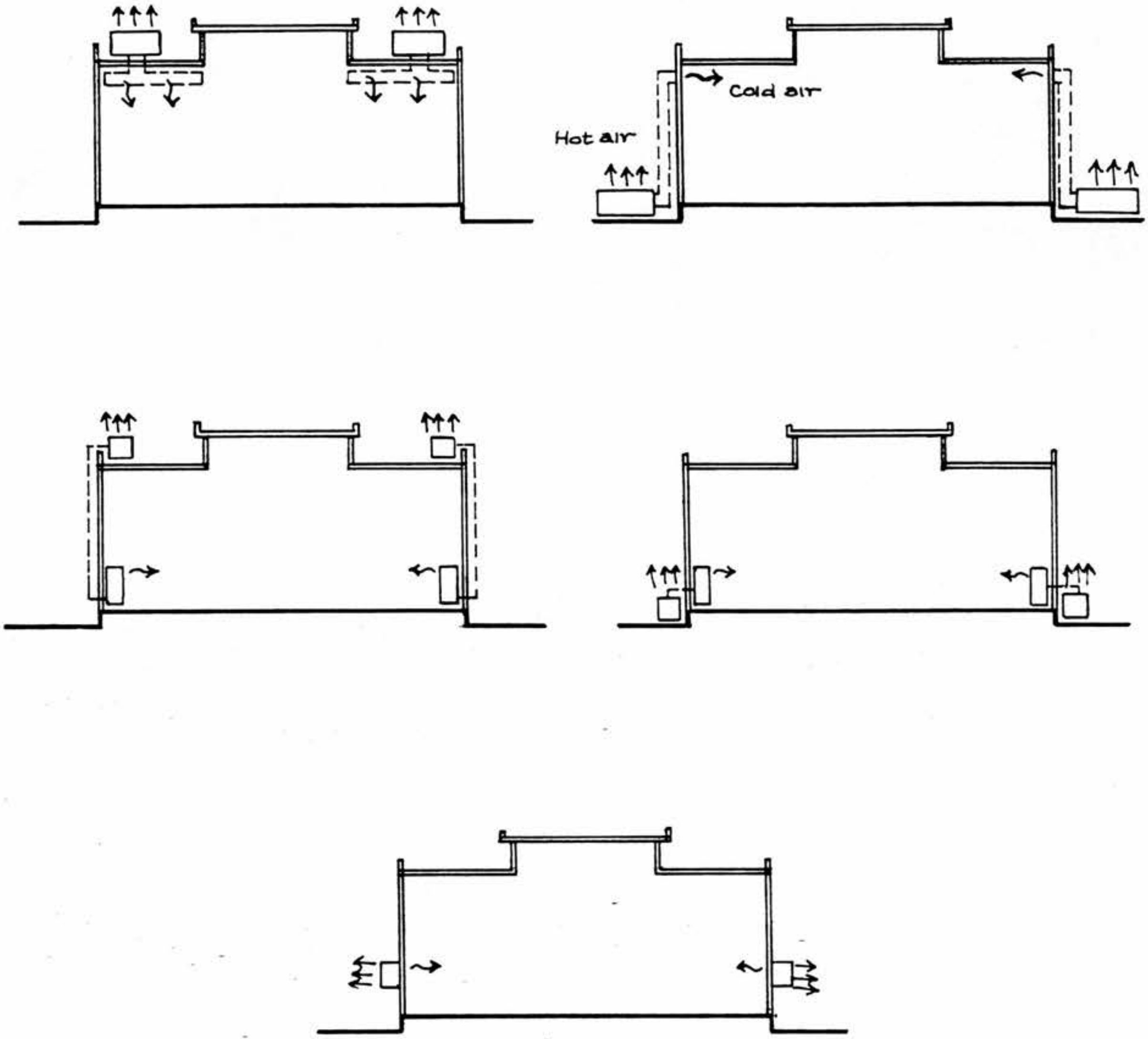

Figure 4.3 Air conditioning systems locations and components

4.3.1.1 Passive cooling systems related to solar radiation interception

4.3.1.1.1 Passive cooling systems for shading

The impact of solar radiation on buildings can be eliminated or reduced by adequate shading[5]. Various systems are available for screening the walls and windows. First vegetation, like existing trees and shrubs, provides the simplest way of protecting a low building or part of it from solar radiation. Horizontal screens are most effective against high sun and normally used in the north and south sides. Some common forms of horizontal screens are roof overhangs, balconies and projecting floor slabs. Vertical screens can be in the form of spaced columns, vertical fins or rotating louvers. These are useful against the low sun on the east and west facades. Combined vertical and horizontal screening -the egg-crate grill, for example can be effective for any orientation depending on its depth and the dimensions of the openings.

The roof can also be shaded only by a horizontal cover (a false roof) extending over the whole roof and projecting beyond it. The false roof can be made of canvas or a simple wooden frame covered by plants.

Whatever type of screening is used should be placed outside, detached from the wall, roof and glazing and be of low thermal capacity materials to ensure quick cooling after sunset. Moreover, it should be designed to prevent both the reflection on to any part of the building and air becoming trapped.

In Jeddah's existing air conditioned mosques, the common systems related to shading are found to be limited to glazing and the roof. A combination of horizontal and vertical screening is used for glazing. It has a grid pattern form made of aluminium known as colestra (fig. 4.4). This colestra is characterised by a shallow depth allowing significant amount of solar radiation to reach the prayer hall. Walls are not shaded, while some parts of the roof are shaded by parapet and domes or clerestory.

In a few existing mosques, a combination of horizontal and vertical screening made of gypsum is used for glazing. The system has a large depth and has, therefore, a high potential to reduce the solar radiation interception. In a few mosques, parts of the wall are shaded by the minaret or by other buildings close to the mosque, the use of trees, projections and exterior 'riwaq'.

4.3.1.1.2 Passive cooling systems related to direction and shape of existing mosque

The orientation of a building is very important in a passive cooling strategy. It is known that the orientation of a building affects the quantities of solar radiation falling on different sides at different times. Both solar radiation and temperature act together to produce the heat experienced by a body or surface. This is expressed as the sol-air temperature which includes 3 components; the outdoor air, solar radiation absorbed by the body or surface and the long-wave radiant heat exchange with the environment.

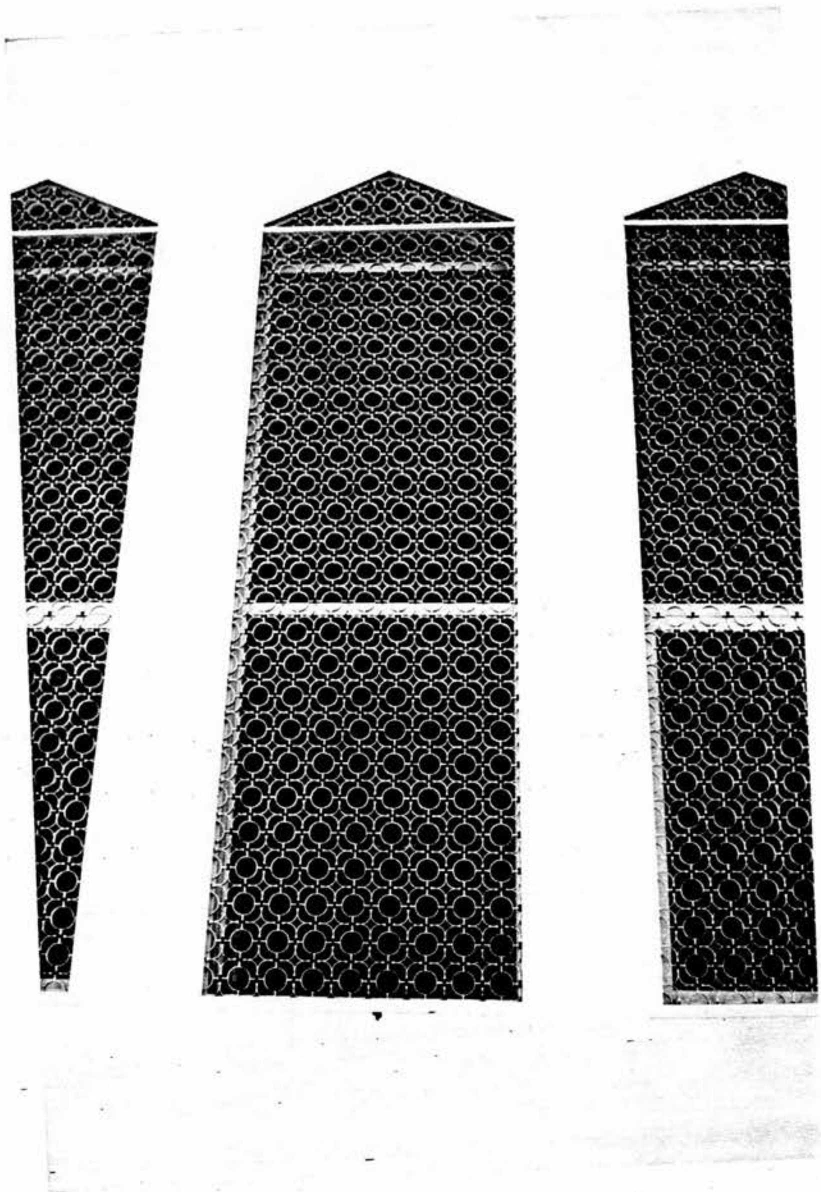

Figure 4.4 Colestra used in windows

Olgyay[6] considered both the sol-air and the heat impact of the diurnal temperatures as important factors related to the issue of orientation. He stated that optimum orientation would reduce radiation to a minimum in the so called overheated period, while simultaneously allowing some radiation during the cool months or the underheated period. As east and west facing walls receive the highest intensities of radiation they should normally be kept as short as possible.

It can be taken as a rule that the optimum shape is that which has the minimum heat gain in summer and the minimum heat loss in winter. The most satisfactory shape is one in which the building is elongated in some general east-west direction and not the squarish shape building[7].

It is difficult to generalise. For instance, although the winter conditions in hot arid regions would permit an elongated building design, the heat stress in summer is so severe that a compromise is required and the traditional solutions is a compact, inward looking building with interior courtyard. In warm-humid environments, emphasis is on the need for shade, for elimination of radiation conditions on the east and west walls and on the need to catch whatever air movement is available. This suggests marked east-west elongation of the building, but if protective shade is available, considerable freedom is possible in building shapes and orientation so that advantage can be taken of any prevailing winds

Existing mosques in Jeddah are either square or rectangular in shape. Very few mosque are octagonal or circular. The direction of these mosques although has to be towards Makkah, rectangular mosques are found to be elongated east-west and north-south.

4.3.1.2 Passive cooling systems related to heat absorption and inward transmission of building envelope

There is a continuous exchange of heat between a building and its outdoor environment[8]. Conduction which may occur through the walls and roof inwards or outwards including the effect of solar radiation on these surfaces. The amount of heat penetrating a building depends largely on the nature of the walls and roofs. During daytime, in hot period, heat flows through these elements into the building, where some of it is stored. At night during cooling period the flow is reversed. Several passive cooling systems related to heat flow are mentioned below.

4.3.1.2.1 Passive cooling systems related to reflection and emission and properties of surface finishes

The reflection and emission properties of surface finishes need to be controlled to reflect away most of the solar radiation and to allow cooling by radiation at night. The ideal surface finish would have very high reflectivity and emissivity. Various building materials with good values of reflectivity and emissivity are available in the market. Generally, it can be stated that light coloured surfaces stay cooler than darker surfaces and therefore white colours should be used for building surfaces in hot climates.

Light coloured surfaces, white and beige, are commonly used in existing buildings. For instance, roofs are covered with gypsum tiles while walls surfaces are either of white plastering or marble tiles.

4.3.1.2.2 Passive cooling systems related to insulation

Three systems are commonly used to resist the flow of heat through building elements. These are fixed insulation, movable insulation, and air-cavity insulation.

Fixed insulation can be used for roofs and walls. It is available in different forms. It is widely used inside the roofs and walls. Movable insulation for roof can also be used and proved to be effective for the natural cooling of a building by Hay and Yellott[9].

The reduction of solar radiation absorption and inward transmission through the use of air-cavity for roofs and walls, ceiling voids or attic space is highly recognised. The cavity represents a resistance in the same way as insulating materials do[10]. Therefore, the downward heat transfer from the external surface to the interior is expected to be reduced if this space is freely ventilated (fig. 4.5).

Walls with an air space were introduced in order to increase its thermal

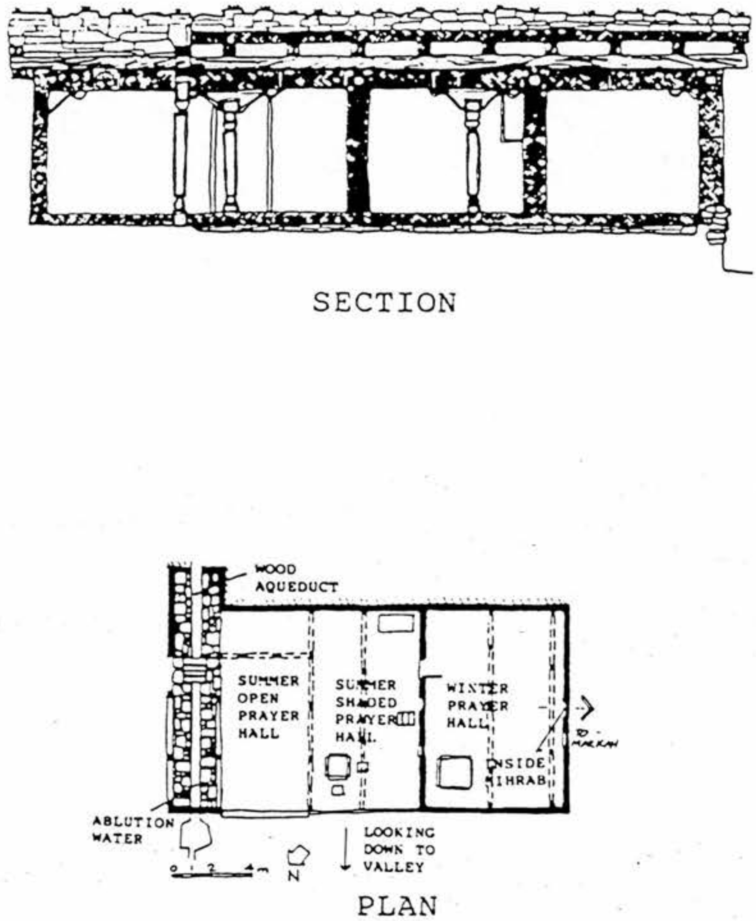

Figure 4.5 Air-cavity for ceiling

resistance. This is because when the inner leaf of the cavity wall is kept dry, the thermal conductivity decreases. If the width of the cavity is kept small, convection currents between the two leaves of the wall can be eliminated and the only way of heat exchange can then take place by radiation. Such a problem can also be overcome by the use of reflective aluminium foil which could be fixed to the outer side of the inner leaf.

In existing air conditioned mosques, only fixed insulation in the form of a water proof membrane is used in the construction of roofs. Though this type of insulation is primarily used against water, it does have some potential to prevent the flow of heat. As far as air-cavity for the roof is concerned, two systems of hollow slab roof and suspended ceiling are used. The former is typically found in existing mosques while the latter is used in a limited number of mosques and for decorative purposes. For the wall, it is built with hollow concrete blocks possessing some sort of air-cavity system. In Lahore[11], Pakistan, the two famous mosques of Zamani and Wazir Khan the air-cavity concept have been adopted in the form of double domed roof representing a good heat resistance from the sun (fig. 4.6). In the Tempe mosque in Arizona, the walls of the prayer hall are protected from the sun by a covered and screened six feet wide projecting balcony representing a sort of air-cavity system.

4.3.1.2.3 Passive cooling systems related to thermal capacity of building

Heavy structures have higher thermal capacity or heat storage value than light structures characterised by thick walls and roofs. Normally the heavy structure helps

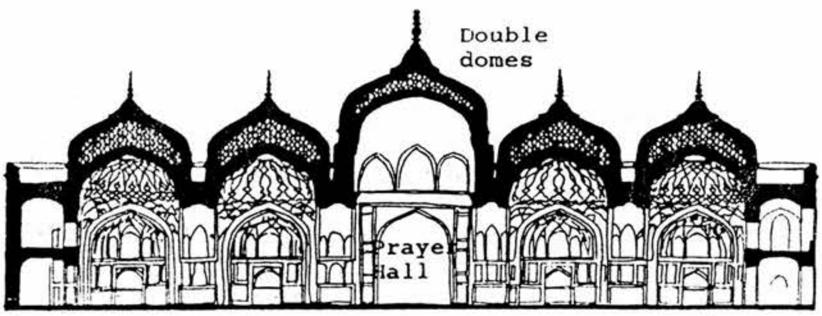

Figure 4.6 Double domed roof system.

delay heat flow to the indoor space. This delay is called 'the time lag'. Under conditions with large diurnal temperature variations the significance of thermal capacity is much greater than that of insulation[12].

Existing air conditioned mosques are commonly light structures made of thin concrete blocks wall and thick roof. Only traditional existing mosques in Jeddah are heavy structures made of thick coral stones. Very few modern existing mosques are heavy ones and made of terracotta.

4.3.1.2.4 Passive cooling systems related to glazing

The incident solar radiation on a glazed area is partly reflected, partly absorbed and partly transmitted. The total solar heat gain through glass can be reduced by the use of special treated glass. Some examples are as follows;

1. Heat-reflecting glass. Such glass is coated with a thin film of metal.
2. Other types of glass have the potential of reducing sky glare and natural lighting considerably.
3. Double glazing may also be used to reduce solar heat gain. It is more effective than the single glazing.
4. A heavier low-emissivity coatings on specialised glazing is capable of lowering air conditioning loads[13].

In Jeddah's existing air conditioned mosques, a single heat and light absorbing glass (Bronze or Grey glass) is commonly used. This type of glass has the ability to transmit 44% of the energy from solar radiation impinging on while reflecting 18% to the outside and the rest is absorbed[14].

4.3.2 Passive cooling systems related to heat removal strategy

In spite of the most favourable arrangement of building form and building elements, some heat will reach the interior of the building. In addition, heat is also generated within the building as a result of artificial lighting, use of machines, etc. Therefore, several systems are employed in mosques to remove heat from the prayer hall with the use of the natural heat sinks of air, water, ground and sky. These passive cooling systems are;

1. Convective cooling systems (ambient air).
2. Evaporative cooling systems (water vapour).
3. Earth Cooling systems (ground).
4. Radiative cooling systems (the upper atmosphere).

4.3.2.1 Convective passive cooling systems

The method of cooling is through the use of ambient air, i.e. ventilation to remove heat from the building interior and convection is the major mode of heat transfer[15]. Two main approaches to cool the building by this method are recognised:

a. Direct convective cooling, through ventilating the space directly when the outside air temperature is lower than the indoor comfort temperature range.

b. Indirect convective cooling, through ventilating the building at night for several hours, consequently the cooled mass serves as a heat sink, absorbing the heat penetrating and generating in the building.

This process of convective cooling is limited to regions where ambient temperature is below the comfort range e.g. below 20 °C. Moreover, it is possible to apply this approach in regions where the ambient vapour pressure in summer is below 15 mmHg, because only then can the human body feel comfortable without feeling air motion at temperature up to about 26-28 °C depending on humidity level[16].

The convective passive cooling systems used in mosques are windows, openings, courtyards, wind catchers, wind scoops (*Badgeer*) and roofs.

4.3.2.1.1 Windows

In Jeddah existing air conditioned mosques, the most common convective cooling systems used are the windows. The sizes of these windows are twice as large as the ones used for residential buildings. They are distributed equally on all sides of the prayer hall arranged in two rows; upper and lower parts. The upper one is always closed and dirty as they are inaccessible while the lower windows are the ones that can be controlled. The window is 1.0m wide and 1.2m high and made of aluminium frame with two equal sliding panels. In Jeddah's traditional mosques windows are even greater in sizes and would cover more than 40% of the walls.

4.3.2.1.2 Openings

Openings on the crown of domes and clerestories are used in mosques as convective cooling systems. For the domes and clerestory operation, during occupied hours the indoor air temperature of a building rises, consequently the air becomes lighter and convects to the top dome or the clerestory, escaping from the small openings. Furthermore, these openings are also used to provide fresh air to the prayer hall. The clerestory with its openings are typically used in existing mosques but the openings are permanently closed with aluminium framed windows. The same scenario is found for the openings on the crown of domes.

4.3.2.1.3 The courtyard

The courtyard is considered to be one of the important convective passive cooling systems adopted in mosques. It is an internal enclosed space open to the sky with spaces for praying around it on two, three or four sides. These spaces look inwards towards the court approaching natural daylight and ventilation. The provision of ventilation via the courtyard is performed in three ways. First during the night, the cool air descends into the courtyard and flows into the surrounding spaces, displacing the hotter air and cooling the floors, the walls, roofs and ceilings. Secondly, when the sun directly strikes the courtyard floor, as a result of direct radiation, the warmed air begins to rise, creating convection currents in the spaces adjacent due to the leaks of air to the courtyard; which could enhance further comfort. This process encourages the courtyard to act as a chimney by exhausting the hot air and replacing it conventionally by the cooler air drawn through the entrance lobby from the narrow street. This function cools the mosque by exchanging the cool air between the street and the courtyard and the spaces around the courtyard. Finally, when the sun sets, the external air temperature drops and the courtyard starts to irradiate the heat to the clear sky, allowing cooling air to flow and descend into the building. The courtyard has always been used as a place for praying during evening prayers.

The courtyard system has been used in Jeddah's mosques for a long time. The system has been adopted in all old and a few new mosques. It is located in the centre and has been recently covered with glass pyramids or canvas. This recent trend is as a consequence of the use of air conditioning.

4.3.2.1.4 The wind-catcher

The wind-catcher is another convective passive cooling system used in mosque architecture. It consists of a shaft rising high above the building with a windward opening to catch the prevailing winds. The shaft is an air cavity between two skins of a party wall. It has an inclined air scoop at its upper part to direct the air flow downward into the building. The wind-catcher is normally built above the Mihrab.

Under night clear sky conditions the internal party walls of the shaft are cooled naturally. During the day their shielded location enables them to act as a cooling element to the interior. In addition air passing down the shaft is cooled by convection when it contacts the internal surface of the party wall. Under sufficient velocity pressures the air is pushed into the building. It slows down and ventilates the internal space. As the ordinary windows are required to be closed during cooling ventilation the air escapes through vents placed high above the inlet opening of the shaft.

Best examples of these wind-catchers are found in Iranian mosques (fig. 4.7) and medieval Cairene mosques[17,18]. These wind catchers are never used in Jeddah's mosques. Only in one mosque (Al-Ruwais Mosque) in Jeddah, has a wind-catcher with contemporary character in a form of consecutive series of catenary vaults has been used. This system has recently been discontinued due to the installation of air conditioning systems in the mosque.

4.3.2.1.5 The open wall *Badjeer*

The Badjeer is a convective passive cooling system used in mosque architecture. Its main functions are to channel the breeze that blows in the direction of the wall by deflecting it downward into the prayer hall by the recessed walls, and allow

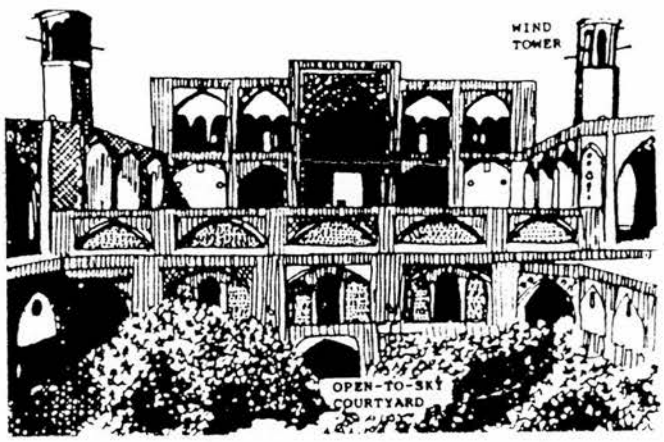

Figure 4.7 Wind-catcher in Iranian mosque

Source: A. Ibrahim, "Mosque Architecture and the Physical Environment", Energy and Buildings for Temperate Climate, ed. E. Fernandes and S. Yannas, 1988. p. 96.

sufficient light to enter directly. The open wall Badgeer is constructed by two recessed parts of the same wall constructed on top of each other and forming an opening of approximately 30 cm between the two parts of the wall. The lower part of the wall is about 1.2 metre high and the upper part starts where the lower part is terminated, as shown in figure (4.8). The flow of air through the opening is controlled by adjustable horizontal wooden boards which slide in and out of the same level of opening.

The open wall Badgeer has three advantages. First, it encourages the worshipper's attention towards the pray by eliminating any visual access to the outside environment. Secondly, it has a greater area to deflect the breeze into the mosque. Finally, it allows the breeze to enter the prayer hall but not the sun.

4.3.2.1.6 Roof as convective passive cooling system

Roof tops of mosques are sometimes used for evening prayers (see fig. 4.9). The roof is entirely exposed to the cool evening breeze. Some example of mosques adopting this system can be found in some parts of the central region of Saudi Arabia, Saiwah oasis in Egypt, and Mali[19].

4.3.2.2 Evaporative cooling systems

These systems achieve coolness through the remove of heat from the building by the use of water. Principally by allowing water-to-air surface contact, heat in the air

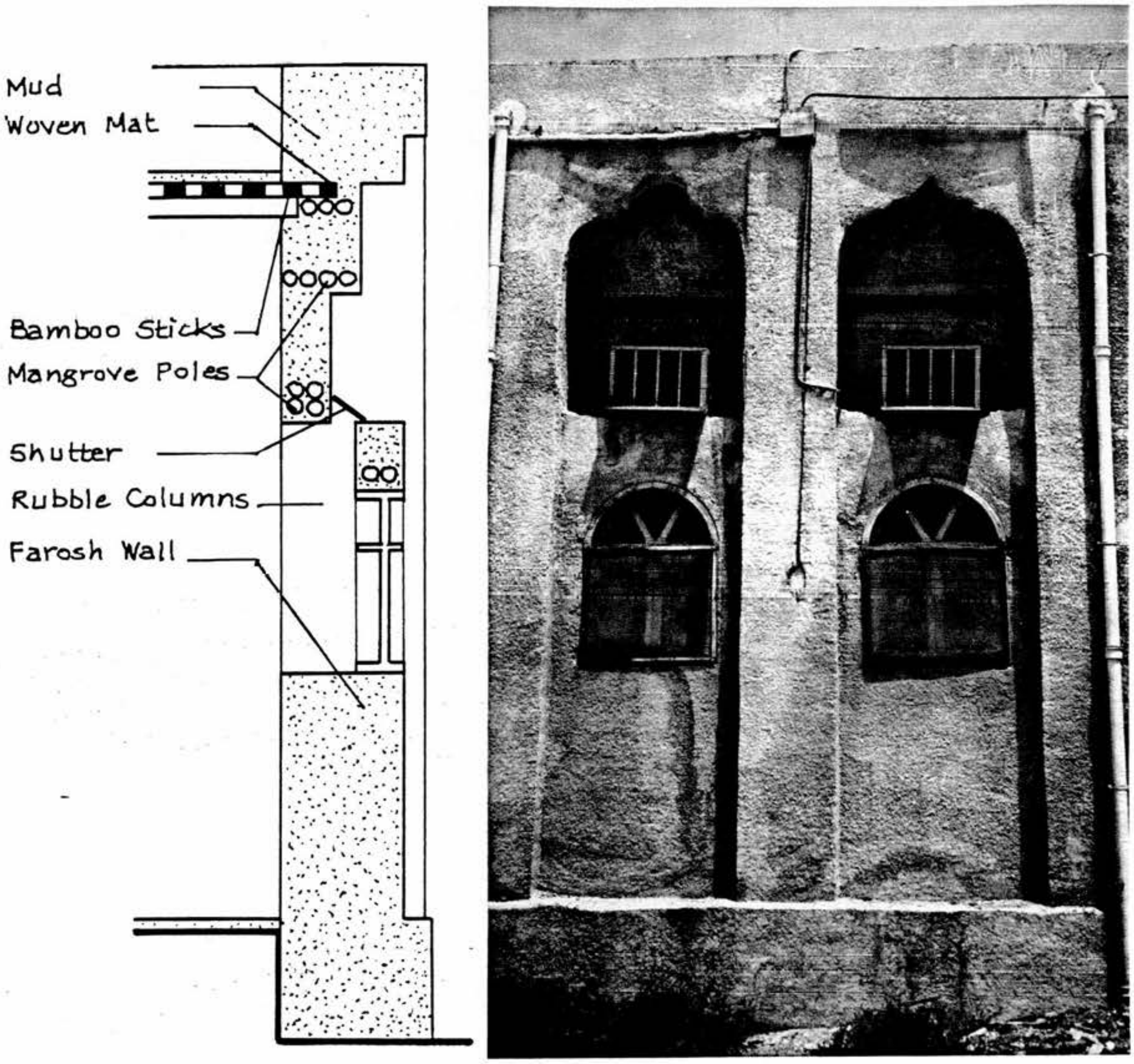

Figure 4.8 Open wall *Badjeer*

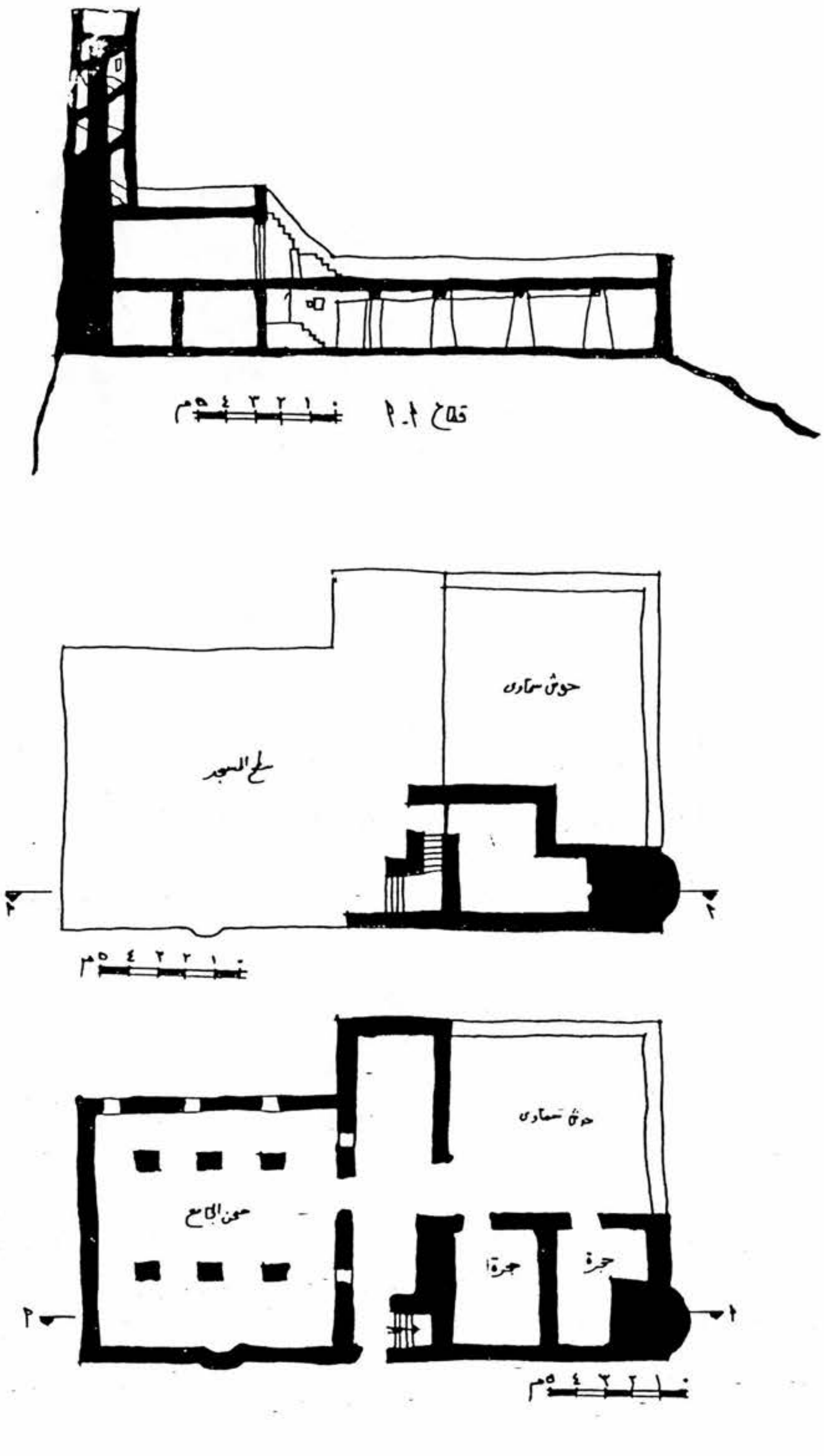

Figure 4.9 Roof as convective passive cooling system

will sink in the water, causing evaporation and thus inducing a temperature depression i.e. cooling the air and increasing the moisture content in the air as well[20].

Basically, there are two main approaches used to cool buildings by water evaporation:

1. Direct evaporative cooling: to cool directly, by evaporation, the outdoor air which is introduced into the building.
2. Indirect evaporative cooling: to cool by evaporation a specific element of the building such as the roof. This element then serves as a heat sink and absorbs through the ceiling all heat penetrated or generated.

The process of evaporative cooling is dependent on the wet bulb temperature of the ambient air. The system is therefore applicable only in regions that have an average wet bulb temperature of less than 20 °C in summer.

Water fountain, *Salsabeel* and water pond were typical evaporative cooling systems used in traditional mosques. They are normally located outside the mosque. These systems have two functions; to provide water for ablution before entering the mosque and to help cool the air before entering the prayer hall. In most of today's mosques these systems can hardly be seen and when found they are just employed for aesthetic purposes. In Jeddah's mosques, these systems are not used and only one mosque is found to use indoor water fountain, such as in the Al-Harithy mosque (fig 4.10).

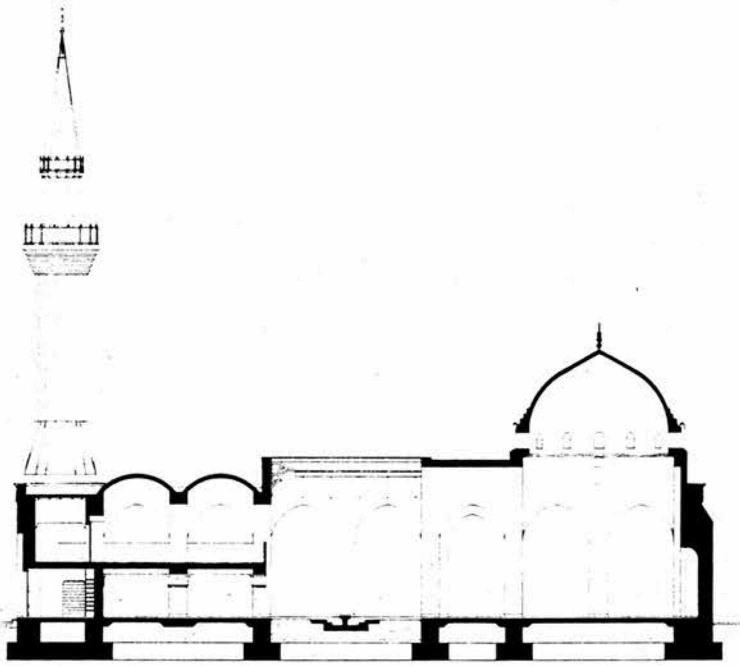

Figure 4.10 Indoor fountain in Al-Harithy mosque

4.3.2.3 Earth cooling systems

The earth mass under, around and sometimes above the building can serve, in most regions, as a natural cooling source for the building either in an active or passive way. In summer, the soil temperature, at a depth of few metres, is always below the average ambient temperature and below the daytime air temperature, forming the potential for serving as a heat sink[21].

In general the earth cooling methods fall into two categories:

1. Direct earth contact; most of the building envelopes; the walls, floors, and sometimes the ceiling are put in direct contact with the earth.
2. Isolated earth contact cooling; the building relies on tubes or ducts to dissipate heat to soil and provide cooling to the building. The air pipes or tubes are to be installed in the soil at a depth of about two metres allowing the air from the building or ventilation air to circulate through them.

Typically found in Jeddah's air conditioned mosques is the direct contact through the floor. Figure 4.11 shows this contact and the building materials involved. Practices on other forms of contact in mosques are as follows:

1. Direct contact with the earth through walls and floors. Best examples are the mosques in the Najd area in Saudi Arabia.
2. Direct contact with the earth through walls, floors and roofs. Best examples are the mosques in south Tunisia (fig. 4.12).

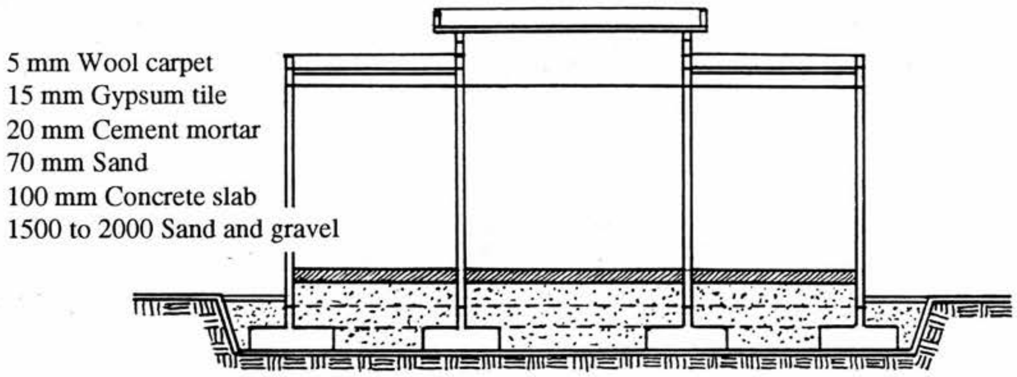

Figure 4.11 Typical earth contact in Jeddah's mosque

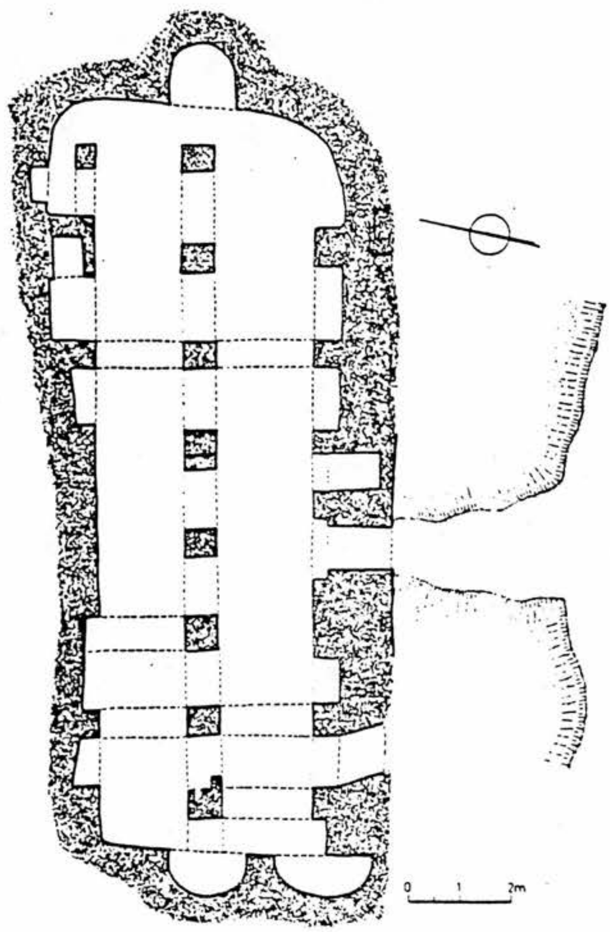

Figure 4.12 Mosques in south Tunisia (direct earth contact).

4.3.2.4 Radiative passive cooling systems

The sky has a temperature of 460 °F (237.8 °C) below zero, therefore, it provides a potential heat sink for cooling[22]. Any element of the external envelope of the building which "sees" the sky can lose heat by the emission of long wave radiation (with peak radiation at a wave length of about 10 microns) and can be cooled to lower temperature below ambient air at night.

This type of process depends mainly on three factors. These are the temperature difference between the emitting surface and the ambient air, the angle of the radiating surface, and the water content of the atmosphere.

The utilisation of the long wave radiant loss for cooling of buildings are possible under two major approaches:

1. Direct cooling of a storage mass (usually the roof) at night and protecting it from solar radiation and hot ambient air during the daytime.
2. Utilising special lightweight insulated radiators to cool down ambient air or water first and then using the cooled medium to cool a specific thermal storage such as rock bed, roof pond, water bags, etc.

In Jeddah's mosques, commonly the direct approach is used. Mainly flat roofs with central clerestory and walls are in direct contact with the ambient air. Few practices of roofs with domes are found in Jeddah's mosques. Bahadori argues that the curved surfaces are easily cooled by radiation to the clear sky and has a larger convection heat transfer area and transfers heat more efficiently than a flat roof[23].

4.4 Observations on active and passive cooling systems used in Jeddah's existing mosques and the need for discovering the potential of improving passive cooling systems

From the above discussion, three important points can be outlined:

1. The mechanical cooling system seems to be most welcomed and widely used in either old or modern existing mosques in Jeddah. This system is very effective in improving the internal environment of the mosques, but it affects the environment in three ways:
    a. Emitting too much CO_2 due to the high energy used to run the system.
    b. Emitting CFCs from the compressors normally used in the system.
    c. Drain out heat.
2. It would be unrealistic to expect all mosques to be cooled passively and the use of mechanical cooling systems to be completely abandoned, yet it is possible to minimise the cooling load in order to reduce these three emissions of CO_2, CFCs and heat.
3. Both modern passive cooling systems such as insulation, glazing, shading devices and traditional passive cooling systems are used in existing mosques. Unfortunately, those modern ones were used ineffectively due to the lack of understanding. Therefore, there is a need for discovering the potential of improving these passive cooling systems.

In this chapter, the different passive and active cooling systems used in existing air conditioned mosques have been discussed. The discussion involves those systems used in Jeddah and other parts of the world under similar climatic conditions. In the following chapter, the intention is to determine those passive cooling systems which need improvements as a major step in defining the necessary improvement measures.

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CHAPTER FIVE: THE DETERMINATION OF PASSIVE COOLING SYSTEMS WHICH NEED IMPROVEMENTS

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CHAPTER FIVE: THE DETERMINATION OF PASSIVE COOLING SYSTEMS WHICH NEED IMPROVEMENTS

5.1 Introduction

In establishing the proposed passive cooling improvement measures, the passive cooling systems in mosques have been reviewed and evaluated in the previous chapter. In this chapter, the determination of those passive cooling systems which need improvements will be addressed. The chapter also covers the two subjects of the selection of case study mosques and the users behaviours towards saving energy and the environment.

5.2 The need to survey the existing air conditioned mosques to determine the passive cooling systems which need improvements

Environmental and behavioural studies have shown a rapid development in recent decades. The analysis of the relationship between human behaviour and the physical environment has attracted many researchers from many fields in the social sciences, such as psychology, sociology, geography and anthropology, and from the environmental design fields such as architecture, urban and regional planning, and interior design[1]. Research on environment and behaviour has often dealt with applied, real-world problems of environmental design as they have treated basic theoretical issues.

The basic goal of most of the social science and environmental design surveys is to produce an accumulating body of reliable knowledge identifying problems which cannot be solved by present day knowledge[2]. Such knowledge would enable the researchers to explain, predict and understand empirical phenomena that interest them. Furthermore, a reliable body of knowledge could be used to ameliorate the human condition and the standard of living in clean environments.

The ultimate purpose of this present survey is to produce reliable information about the existence of high air conditioning energy consumption as well as high emissions of atmospheric pollutants associated with the stock of mosques in Jeddah. The survey also aims to review the different air conditioning energy parameters as related to air conditioning systems, setting, occupancy and building. Moreover, the study would enable the author to select a number of mosques which can represent the mosque stock in Jeddah for detailed study.

This part of the chapter is devoted to the presentation of the survey conducted by the author on the mosque stock in Jeddah. The method by which the survey was carried out, the scope of the survey, and the summary of the fieldwork procedures are discussed, as are the results of analysis of the survey and the computer programs used for the analysis.

5.2.1 Methodological elements of the survey as related to cooling issues

Surveys and data analysis are essential elements in most social science research.

Usually, social science data is obtained when investigators record observations about phenomena being studied; however, not all phenomena are accessible to the investigator's direct observation. Therefore, the data should be collected through asking the people who have experienced certain phenomena to reassemble these phenomena. The obtained responses establish the data upon which the finding of the study will be based. To attain the maximum possible information, this study has implemented the following survey research elements as sources of its data collection; (1) archives survey, (2) observing technique (3) personal interviews

5.2.1.1 Archive survey

The archive method is useful in gathering information that cannot be obtained through other research methods. Archival search for this study took place in libraries, bookstores, government agencies and architectural offices. The search covered books, journals, surveys, reports and newspapers reports.

Historical and documentary search through Arabic literature and diaries of European travellers in the last two centuries in the Middle East provided valuable information about the historical aspects of cooling in mosques. It was helpful in deepening the understanding of cultural reaction to the concept of cooling. Moreover, government archives provided information about the process of change in the cooling of mosques. The search also included looking at data that someone else had gathered for other purposes and turning them into information useful for this study.

Understanding contemporary design ideas of mosques and other related facilities was mainly obtained through searching drawings and plans, reports and surveys collected from archives of government agencies and architecture firms. Reviewing local newspapers and magazines provided a unique and extremely helpful source of information. Newspapers and reports about local issues helped in generating new ideas and supporting some arguments in the research. The accumulation of this archival search was used throughout this study.

5.2.1.2 Site Observing technique

Observing means watching, this method helps to delineate the relations between cooling systems used and the design setting. It also provides a clear picture of the forms of interaction between mosques and other related facilities such as the residences of Imam and Muaddin and ablution quarters. As an objective appraisal of the study, observation played a major part in the reconnaissance of the actual environmental conditions as well as the management's behaviour in the surveyed mosques. These reconnaissances were made to generate information regarding (i) design characteristics such as social, climatic and economic conditions; (ii) physical characteristics such as type and size of the mosque, building materials, construction methods and equipment; (iii) users' characteristics such as sex, age and social and economic conditions.

Conducting an observational technique (field study) is usually a long procedure and needs an adequate budget. On the contrary, the time and budget for this study was limited.

Photography, a technique usually used in observational techniques for recording events and facts was considered in this research. The surveyed mosques were photographed during daytime when they were free of users.

5.2.1.3 Personal interviews

The simple function of personal interviews is a face-to-face interpersonal role situation in which an interviewer asks respondents questions designed to obtain answers required for the research completion[3]. Most interviews are as a result of oral communication between the researcher and the respondent. In this research the respondents are the management staff of the surveyed mosques. As far as this study is concerned, most of the questions were factual ones. They were designed to elicit objective information from the respondents regarding the time and scale of the cooling systems used.

The interview section represents the unsystematic part of this study. In this section, data were collected by means of personal interviews and open informal discussions with public authorities and the management staff of the surveyed mosque. Some of these meetings were pre-arranged, while most of them happened as an unplanned meeting during the process of data collection.

5.2.2 The scope of the survey

Usually data is collected in order to draw general conclusion about certain topics. Only rarely does a study include observations of all respondents or even all events that are required for generalisations. Therefore, in this study, to arrive at an accurate estimate of parameters, the following requirements were effectively dealt with: (1) the definition of the studied area, (2) the size of the sample and (3) the sample frame.

5.2.2.1 Study area

One of the first problems which should be considered in any survey procedure is determining the number of mosques involved in the survey. For this reason, the mosques were defined precisely by specifying the area which the author would like to investigate. The study area was specified as the Western region of Saudi Arabia due to the rapid development which the area has experienced and due to the presumed high environmental impacts. The study sample was drawn from the largest city in the region which was Jeddah city (figure 5.1). The selection of this city was motivated by the following: firstly, in terms of practicality, limiting the study of mosques to a particular area rather than the whole city makes it more feasible due to the limited resources and time and secondly and most importantly, is that the city is the most developed city in the region and it accommodates the highest numbers of air conditioned mosques.

5.2.2.2 Sample size

Once the study area has been defined, the sample that is required to represent the study area should immediately be drawn. Usually, adequate surveys require large sample sizes of varied characteristics that sufficiently reflect the variation which might exist in all air conditioned mosques in the city. However, a large sample cannot be achieved in this study due to its scope and nature, especially if the limited availability of

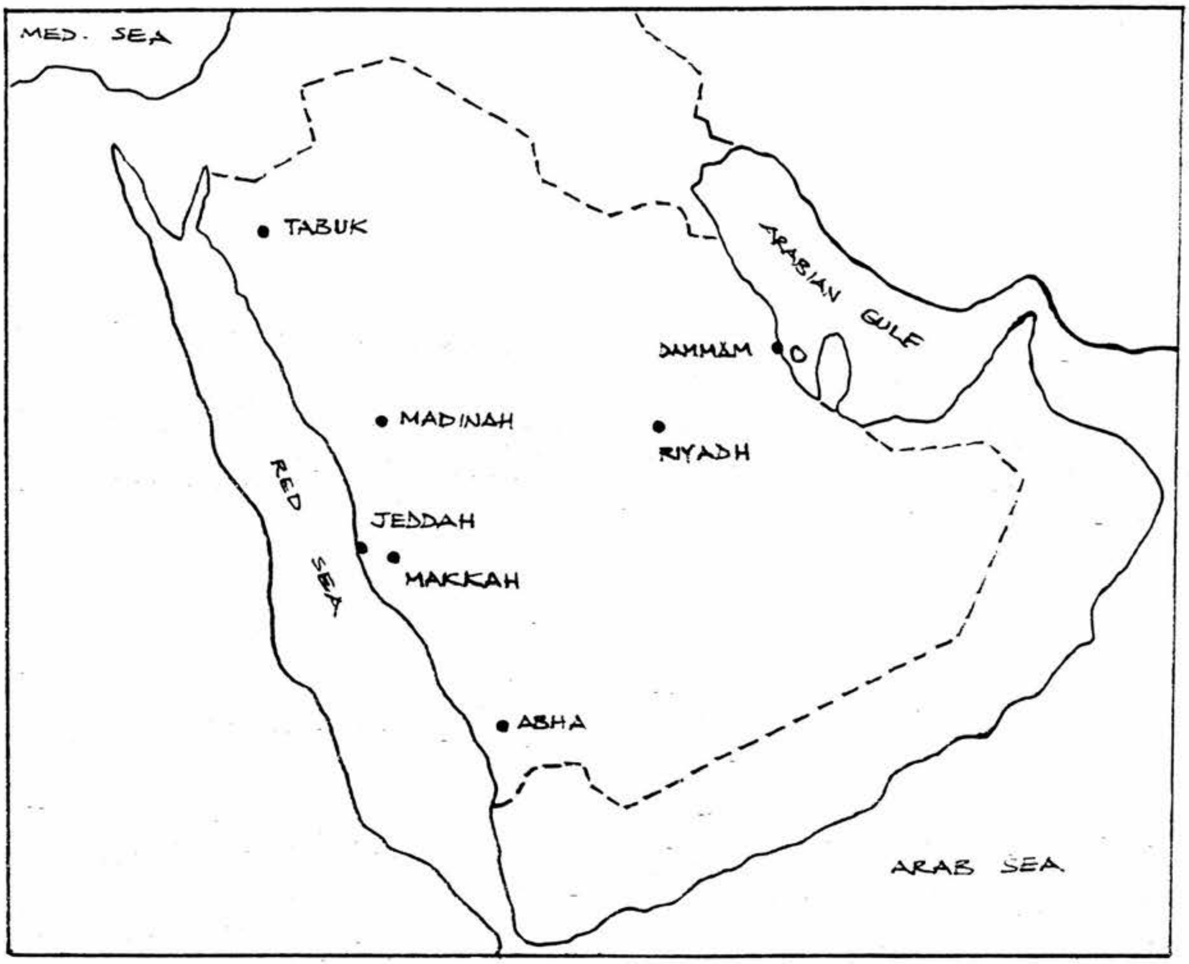

Figure 5.1 Location of the city of Jeddah, Saudi Arabia

resources is considered.

By employing some of the sampling techniques, a total of 48 air conditioned mosques were selected (5%) from a total of 960 air conditioned mosques exist in Jeddah. All 48 mosques were surveyed with a complete interview respondents in 45 days.

5.2.2.3 Sample frame

The sampling frame is a systematic procedure involved in selecting a sample from a complete list of sampling units. The structure of the sample frame in this study was based upon simple random sampling. Actually, this sampling method gives each of the sampling units of mosque an equal chance of being selected. Unfortunately, the complete list of mosques in Jeddah was not available. The only possible way to get it is to consult the electricity company with the actual subscription numbers of each 970 mosques in the city. This was definitely impossible to do as far as time and resources are concerned. A linear section in the city has been selected (figure 5.2). The section contains different types of air conditioned mosques (old and new) in the city as recommended by the General Directorate for Awkaf and Mosque in Jeddah Region. The locations of all the mosques in the section has been identified with the use of aerial maps provided by Jeddah Municipality. Several site visits to these mosques have been carried out and a photograph of each one has been taken as well as general physical discriptions were recorded. After analysing carefully these mosques, 48 mosques were selected from this section.

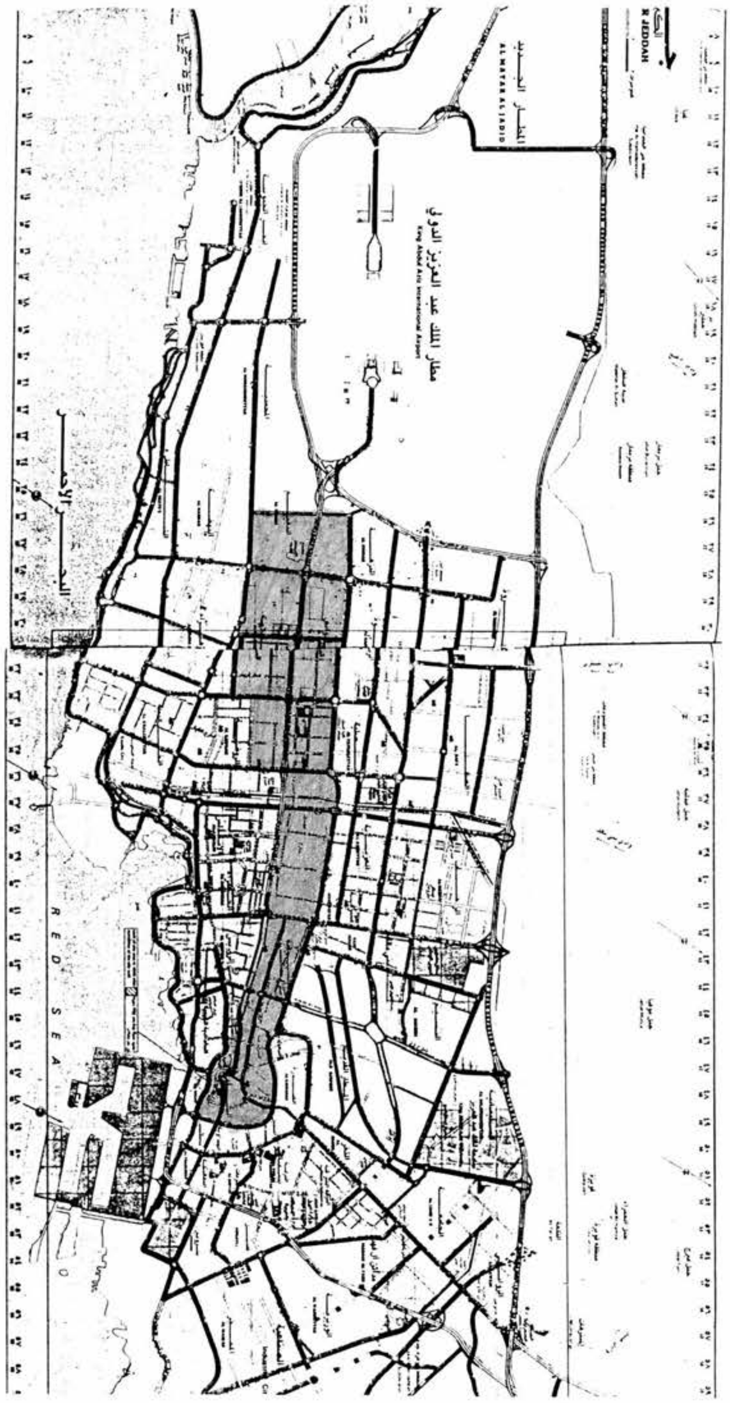

Figure 5.2 The selected section for the study, Jeddah, Saudi Arabia.

5.2.3 Fieldwork procedures

The survey was carried out by the investigator during the late summer of 1991. The actual fieldwork was divided into two major surveys, the general survey which was mainly concerned with collecting information about the main sample, and the detailed survey which was only concerned with the selected case studies.

Usually, practical experiments and surveys are time consuming because of the overlapping procedures; however a clear and well prepared procedure can reduce the time and effort required. To save time and effort, the author believed that this survey needed a clear strategy of this fieldwork and an early preparation of the necessary aspects before the actual survey began.

5.2.3.1 The strategy of the fieldwork

The strategy of the fieldwork was established to achieve the author's objective in investigating the different cooling systems that contribute to the environmental hazard through the emissions of CO_2 and CFCs. The strategy was structured by specifying the information needed to be collected, how it was going to be collected, and the purpose of collecting this information (Table 5.1). It specified the way of conducting the investigation. The investigation was carried out on the mosques which had been air conditioned recently (old and new mosques) and the range which was investigated is 48 mosques.

Table 5.1 Summary of the information needed, the method of collection and the purposes of collection

A. Building, users, setting

1. The volume of the cooled space of each mosque	From Jeddah Municipality (maps and detailed drawings)	To know the exact volume inside the mosque that is cooled mechanically
2. Shapes of the mosque	From Jeddah Municipality (maps and detailed drawings)	To find out the different shapes of existing mosques
3. Type of building material	From physical observation	To discover the different builing materials used in order to estimate the performance of every part of the building
4. Openings	From Jeddah Municipality (maps and detailed drawings)	To survey the size of the opening and to find out whether the windows are single or double glazed in order to calculate the heat gained through the windows
5. The physical size of the mosque in details	Physical measurements	To find out the area of the mosque and the length of different elevations in order to know the amount of the exposure on the mosque
6. User's (numbers and sex)	From Jeddah municipality (maps and detailed drawings) and physical observation	To discover the numbers and sex of worshippers using the mosque
7. Contact with earth	From physical observation	To verify the presence of direct earth cooling system in each mosque
8. Presence of water bodies	From physical observation	To verify the presence of any evaporative cooling systems
9. The use of natural ventilation	From the interview	To discover the use of natural ventilation in each mosque
10. Setting	From physical observation	To discover the types of surfaces around the mosque

Table 5.1 (continued)

B. Active cooling systems

1. Different A/C systems in each mosque	From observation	To discover the different probabilities of energy consumption
2. Management of a/c systems	From the interview	To discover the numbers of a/c systems and their usage throughout the year
3. CO_2 and CFCs emissions as related to a/c	From the interview	To discover the environmental awareness of the management
4. Use of a/c over a year	From the interview	To find out the duration of using a/c on yearly basis
5. Refrigerants reinjection	From the interview	To discover the scale of CFCs leakage and the frequency of re-injecting existing systems with refrigerant
6. Type and amount of refrigerant in each system	From observation	To find out the actual amount and the type of CFCs used

C. Energy issues

1. Air conditioning energy consumption for the whole year	Reviewing the electricity company bills	To calculate the average annual air conditioning consumption for a mosque
2. Type of energy used in each mosque	From interview and the physical observation	To know the percentage of energy used in cooling with respect to the other uses
3. Multiple subscriptions	From observation	To find out the actual energy consumed by the mosque

5.2.3.2 The preparation of the fieldwork

The preparation of the fieldwork started with correspondence and communications with the different Government Departments involved in the survey directly or indirectly, as follows:

1. An early communication was made with both the Saudi Arabian Educational Attaché and King Abdulaziz University, School of Environmental Design to acquire their approval in supporting the fieldwork. This started five months preceding the survey.
2. Only the author was involved in the data collection process. An authorisation letter was issued to entitle the author to interview the mosque management; the letter described the typology of the survey and illustrated the name and occupation of the investigator, was signed by the director of the General Directorate of Awkaf (endowment) and Mosques in Jeddah.
3. Three to four mosques were investigated each day. The author was conducting the survey between 10:00 am and 04:30 pm. As far as the interviews with the mosque management is concerned only two to three interviews were possible on a daily basis. This was due to their presence only during the prayer times.
4. By using a systematic way of coding (which is a system of writing in numbers or letters to abbreviate the length of data) the data was recorded on coding sheet (Table 5.2). The data in the coding sheets was later transferred onto the mainframe computer in the University of Edinburgh.

Table 5.2 The coding of information collected

mosqn	Mosque name	Actual name
acengyy	Annual air conditioning energy consumption	Actual numbers in kwh 0 (not high or low) = up to 25000, 1 (slightly high) = 25001 to 50000, 2 (high) = 50001 to 100000, 3 (extremely high) = over 100000
egybase	Annual energy base	Actual numbers in kwh
acengym	Annual air conditioning energy consumption per cubic metre	Actual numbers in kwh
CO_2acgy	CO_2 annual emission as related to air conditioning energy	Actual numbers in kg
CO_2acgym	CO_2 annual emission as related to air conditioning energy per cubic metre	Actual numbers in kg
actype	Type of a/c system	1 = window package, 2 = central, 3 = split, 4 = mix
age	Years of using air conditioning	Actual numbers 1 = 1-3, 2 = 4-6, 3 = 7-9, 4 = 10 or more
acusage	Use of a/c systems	1 = never switched-off for four weeks throughout the year and when used, the scale of the systems involved are as follows ; 1/4, 1/2, and all of the systems when approaching summer times
refregi	Refregirent reinjection	1 = every 5 to 6 years
applia	Number of appliances	Actual numbers, 1 = up to 30, 2 = 31 to 60, 3 = 61 to 90, 4 = 91 or more
setting	Mosque setting	1= isolated with light greenery around 2= isolated with heavy greenery presence
ttlworsh	Total numbers of worshippers	Actual numbers, 1 = up to 500, 2 = 501 to 1000, 3 = 1001 to 1500, 4 = Over 1501
windows	Area of windows	Actual numbers in square meters

Table 5.2 (continued)

mosqshp	Mosque shape	1 = Square 2 = Rectangle 3 = Octagonal
volcolsp	Volume of cooled space (prayer hall)	Actual numbers in cubic metres 1 = 2000 or less, 2 = >2001 and <5000, 3 = 5000 and more
infiltra	Reducing infiltration	1 = no, 2 = yes
exposure	Number of exposed surfaces to the outdoor environment	1 = four surfaces, 2 = less than four surfaces
U value	Thermal transmittance values of mosque fabric	1 = high, 2 = low
partpry	Using part of the prayer hall	1 = no, 2 = yes
ventila	Allowing cross ventilation at night on daily basis	1 = no, 2 = yes
earthcon	Earth contact	1 = all of the mosque 2 = part of the mosque
waterpr	Water pool presence	1 = no, 2 = yes

5.3 Computers used in the analysis

The statistical analysis of this study was carried out with the use of SPSSX (The Statistical Package for Social Sciences). This program has the capability of manipulating and analysing the data. It was used to feature various statistical procedures, ranging from simple descriptive measures such as simple plot, frequency distribution, mean, and cross tabulations, to multivariate methods, such as multivariate analysis of variance and multiple regression. Finally, the program can take the data from the file and turn it into meaningful information, supported by illustration in graphical forms. A set of commands is required when using this package in order to define, analyse, and display the data. The program deals with the data in the form of a spreadsheet layouts[4].

The data of the survey (Table 5.3) is converted onto a row data file containing mainly numbers by using the coding system. Two things were then constructed (i) the file definition which provides information about the data file, and (ii) the variable definition which gives information about the location, structure, and meaning of the data on the file. These two things are very important to do so as to make this raw data meaningful for the computer as well as for the final results.

5.4 Results and analysis of the survey

The coded collected data were built into computer files and tabulated using SPSSX program. Analysis and presentation of the data were based on two main

Table 5.3 Example of some of the data collected

mosqn	volcol	egybase	acengyy	acengym	coacgy	coacgym	ttlworsh
Zaid A.	1502	8400	15231	10.14048	898.629	0.59	303
Robo'a	821	1200	8070	9.829476	476.13	0.58	108
Zahrasa	1105	13500	27023	24.4552	1594.357	1.44	234
Majd	1862	5400	47420	25.46724	2797.78	1.5	312
Omar B.	1662	8904	59155	35.59266	3490.145	2.1	455
Forkan	1947	11484	72675	37.32666	4287.825	2.2	566
Shafi	2087	9072	18682	8.951605	1102.238	0.52	378
Momenen	2606	10512	26501	10.16922	1563.559	0.6	520
Rida	3859	13200	46123	11.95206	2721.257	0.705	741
Noorba	2985	16848	36174	12.11864	2134.266	0.715	644
Alkhairat	4149	20100	51335	12.37286	3028.765	0.73	848
Tayyaren	4534	24336	58404	12.8813	3445.836	0.76	828
N. Zahid	4872	23076	62757	12.8813	3702.663	0.76	668
Z.Omar	3486	18432	50222	14.40677	2963.098	0.85	638
Angari	3078	23760	56789	18.44997	3350.551	1.08	520
Huda	4866	37368	100618	20.67776	5936.462	1.22	626
Ekhlas	4360	46440	91629	21.01583	5406.111	1.24	750
Tho. N	2244	13536	48236	21.49554	2845.924	1.26	436
Alkhair	4075	14400	89788	22.03387	5297.492	1.3	833
Bamihrez	3172	22824	72878	22.97541	4299.802	1.35	660
Harithy	3249	12825	75111	23.11819	4431.549	1.36	452
Tawheed	4760	24336	109757	23.05819	6475.663	1.36	895
Hanafi	4085	37740	95933	23.48421	5660.047	1.38	560
Bokhari	2597	9372	62726	24.15325	3700.834	1.42	505
Ibn Abs.	3768	22500	90687	24.06768	5350.533	1.42	859
B. Obaid	4518	108738	108738	24.06773	6415.542	1.42	941
P. Fahd	2877	42192	69930	24.30657	4125.87	1.43	517
Sowayeg	3390	50208	83729	24.69882	4940.011	1.45	664
N. Eman	4760	24200	120210	25.2542	7092.39	1.49	748
Mimar	2653	36996	68798	25.93215	4059.082	1.53	338
J. Tayyar	2050	9000	55095	26.87561	3250.605	1.58	520
Torki	3383	43200	100343	29.66095	5920.237	1.75	625
Jamjoom	4250	41544	126059	29.66094	7437.481	1.75	758
Grls. Coll	2031	36144	82616	40.6775	4874.344	2.4	390
Howaish	2044	32556	88688	43.38943	5232.592	2.56	468
Taqwa	2407	16704	105908	44	6248.572	2.6	611
Aalysr	2507	39648	114727	45.76266	6768.893	2.7	625
Alber	3019	32328	143274	47.45744	8453.166	2.8	618
Rahma	6930	40860	64177	9.26075	3786.443	0.55	753
Amodi	6297	33504	64894	10.30554	3828.746	0.608	972
Zahrasha	5681	10800	60661	10.67787	3578.999	0.63	1250
Kayyal	5583	39672	61502	11.01594	3628.618	0.65	689
Shati	5050	54000	103567	20.50832	6110.453	1.21	781
T. Lami	5204	96444	119074	22.88125	7025.366	1.35	755
Salman	5300	97308	133846	25.25396	7896.914	1.49	1049
Bokshan	9267	94464	318847	34.40671	18811.97	2.03	1367
Shoaibi	11488	155771	467314	40.67845	27571.53	2.4	1893
Juffali	10095	163297	479084	47.45755	28265.96	2.8	1429

tabulations:

(1) The simple descriptive tabulations: to investigate the frequency and percentage distribution of the responses in order to define some of the characteristics of the mosque stock in Jeddah. This simple tabulation presents the data in a simple way enabling the non researcher to understand it easily.

(2) The cross tabulation: to test the relationship among different variables, for instance, to test the level of significance between the level of air conditioning energy and the use of insulation in building. The cross tabulation process is the sort of analysis which leads to indirect conclusions resulting from the type of relationship between two or more variables.

5.4.1 The selection of case study mosques

Due to the fact that this study was concerned principally with air conditioning energy in existing air conditioned mosques and the possibility of improving their energy and environmental performance through improving the existing passive cooling systems in these buildings, a considerable amount of time and effort was put into the investigation of the selected case studies.

Definitely at this stage, it was not possible to select one case study representing a large number of mosques due to the range of variables which can hardly be covered by only one case. Therefore, all surveyed mosques were put into several groups and each group is represented individually.

The Ministry of Hajj and Awkaf (endowment) has categorised mosque buildings into two groups; local and Jum'a (Friday) mosques based on (i) the numbers of worshippers and the type of prayers performed. Four hundred persons are proposed for a local mosques (where only daily prayers are performed) and 800 worshippers for Jum'a mosque (where daily and Friday prayers are performed). Unfortunately this criteria cannot be applied in categorising the existing mosques due to the fact that (i) the number of worshippers in these mosques is different and (ii) both daily and Friday prayers are performed in both local and Jum'a mosques nowadays.

A new grouping criteria based on the volume of the prayer hall is proposed by the author as derived from the data collected from the survey conducted for the different existing air conditioned mosques. Three groups are defined. First, those mosques which have prayer hall volumes of less than 2000 cubic metres and are called "Small District Mosques". Secondly, those mosques with prayer halls of more than 2000 cubic metres and less than 5000 cubic metres and are named "Large District Mosques". Finally, those mosque possess prayer hall volumes of more than 5000 cubic metres and are called "Central Mosques". The General Directorate of Awkaf and Mosque in Jeddah area has accepted this classification and approved it to be correct.

Each group was then represented by three mosques with high, moderate and low levels of air conditioning energy consumption and the related emissions of atmospheric pollutants. This would give a total of nine case studies.

After the selection of the case studies was made, official letters by the General Directorate of Awkaf and Mosques in Jeddah Region were issued to the managers of these mosques. The letters introduce the investigator in collecting the data required and conducting the interview.

Due to the circumstances of personal secrecy and management absence, some of the mosques' managers of the selected case study refused to be interviewed and did not allow any collection of data to be taken. In addition, some of the mosques' managers were not available for the interview. In such cases, the second priority mosque (next higher or next moderate or next lower) was selected for the detailed study. Detailed drawings was obtained for each case either from the mosques' managers or from Jeddah Municipality and will be presented in the next chapter.

The investigation shows that the percentage of the large district mosques (more than 2000 cubic metres and less than 5000 cubic metres) is almost twice that of the other two sizes. The survey shows that the large district mosque occupied about 67%, the small district mosques (less than 2000 cubic metres) occupied 12.5% and the central mosques (more than 5000 cubic metres) occupied 20.5% of the surveyed mosque. The results of the survey have helped in introducing for the first time the different classification of existing air conditioned mosques in Jeddah under the criteria of volume, air conditioning energy consumption, CO_2 emission level and worshipper numbers (Table 5.4). The table also reveals the name of the mosque which represents each category and which will be studied in detail in Chapter Eight.

Table 5.4 The different classification of existing air conditioned mosques in Jeddah under the criteria of volume, air conditioning energy consumption, CO_2 emission level and worshipper numbers and the name of the mosque which represents each category

Mosque Category		Mean Volume	Mean AC. Energy	Mean CO_2 Emissions	Mean Worshp. No.	Selected Mosque
Small District Mosque	I-A	1161.5	9.91 Kwh/m^3	0.585 Kg/m^3	205	Zaid Al-Khair
	I-B	1483.5	24.57 Kwh/m^3	1.45 Kg/m^3	273	Al-Majd
	I-C	1804.5	36.44 Kwh/m^3	2.15 Kg/m^3	510	Al-Forkan
Large District Mosque	II-A	3572.25	11.68 Kwh/m^3	0.70 Kg/m^3	658	Al-Rida
	II-B	3586	24.06 Kwh/m^3	1.42 Kg/m^3	642	Ibn Abbas
	II-C	2401.6	44.06 Kwh/m^3	2.6 Kg/m^3	543	Al-Taqwa
Central Mosque	III-A	6122.75	10.16 Kwh/m^3	0.60 Kg/m^3	916	Amodi
	III-B	5184	22.88 Kwh/m^3	1.35 Kg/m^3	861	T. Lami
	III-C	10283	40.84 Kwh/m^3	2.41 Kg/m^3	1563	Shoaibi

5.4.2 User behaviour

The user behaviour and their attitude towards saving energy and emissions of atmospheric pollutants are among the different factors which affects the building thermal and environmental performance. Generally, the level and degree of saving energy and consequently reducing emissions are highly connected to user behaviour and awareness of the necessity for reducing both energy consumption and related emissions. Therefore, the managers' behaviour inside the mosque was observed and recorded carefully. Two important topics received the consent of the managers for publishing.

5.4.2.1 Cooling system usage time and type

Mosques are used at various times of the day and night for different periods of time. Therefore, in order to get a reasonable estimate of the energy consumed by the mosque, the type of the cooling system used and the duration of usage were surveyed. The survey showed that the cooling system is used during the prayers times, Quran teaching sessions, and occasional lectures. The system is normally put on 15 to 60 minutes prior to prayer time and switched off 10 to 20 minutes after the prayer has finished. Moreover, the cooling system is used for almost 11 months and not used in the whole month of January. The numbers of air conditioning units used at a particular time; in a mosque ranges from all units during the summer months and quarter to half of the units for the other months.

There are two types of cooling system used in mosques. The survey showed that 31.25% of the mosques used only air conditioners and 68.75% used both air conditioners and ceiling fans.

5.4.2.2 Efforts to save energy

The survey of 48 mosques has successfully illustrated the problems of energy wastage in mosques. It showed that the managers of these mosque did not use insulation to improve the thermal performance of the mosque. Furthermore, they did not allow cross ventilation to circulate the air and prevent the heat from accumulating in the prayer halls. Finally, they use did not shade the openings properly (see figure 5.3). The efforts made by these managers were very limited in using part of the prayer hall and reducing infiltration.

5.4.2.3 Efforts in saving emissions

The survey showed that the managers are not aware of environmental issues regarding the emissions of the atmospheric pollutants (namely CO_2 and CFCs) in general and as related to mosque in particular.

The survey showed that air conditioners in mosques are usually reinjected with refrigerant gas every 5 to 6 years, i.e. all the refregirant in the compressor has been discharged to the atmosphere within the mentioned period. The reinjection process is normally carried out by unskilled labours.

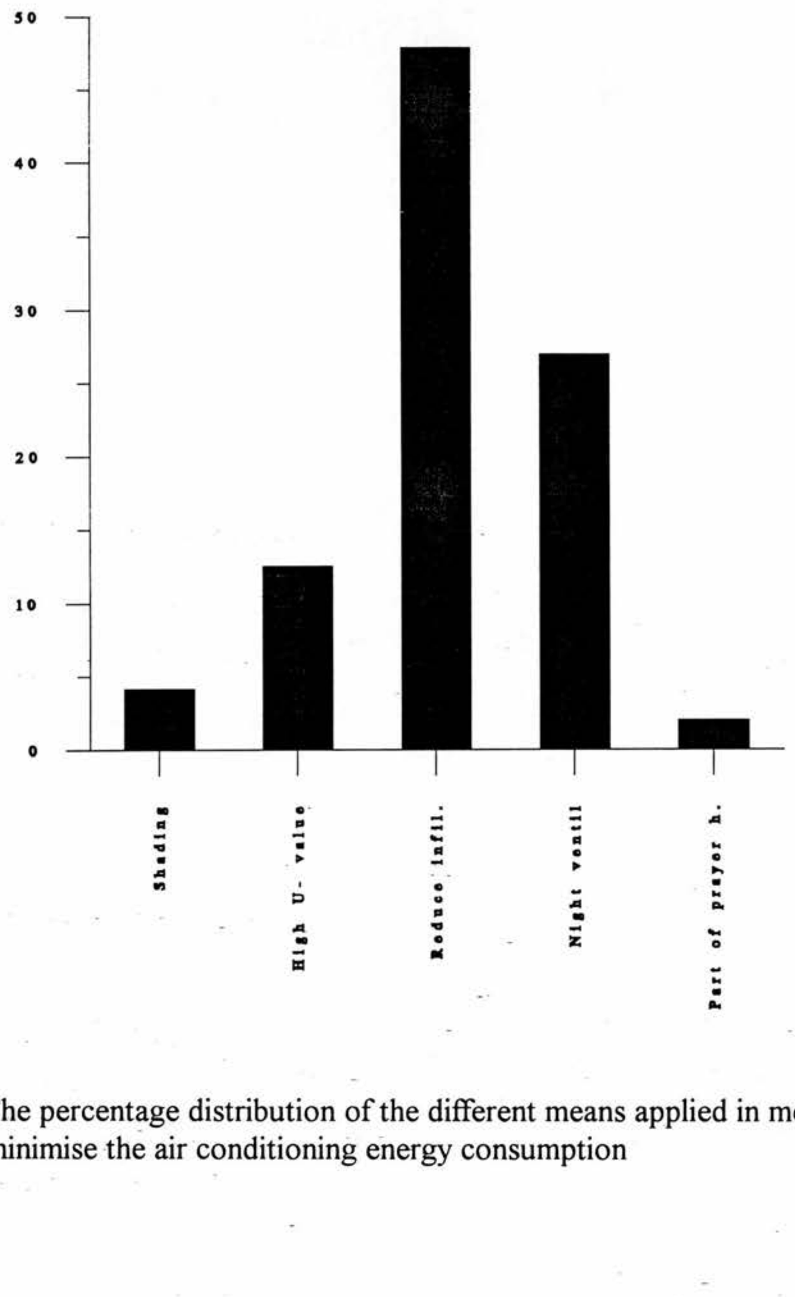

Figure 5.3 The percentage distribution of the different means applied in mosques to minimise the air conditioning energy consumption

5.4.3 Analysis of high air conditioning energy consumption in the mosque and the role of existing passive cooling systems

The analysis indicates that 95.8% of the surveyed mosque has high air conditioning energy consumption (see Table 5.5). This high percentage of high levels of air conditioning energy consumption encouraged the investigator to test this with some of the variables to see the possible relationships involved. Those variables which show strong relationship will be considered as the most ones demanding improvements.

Table 5.5 The number of mosques under different air conditioning energy consmption levels.

Category of a.c. energy	Level of air conditioning energy (Kwh)	No. of mosques	%
Low	<25000	2	4.16
Slightly high	25000-50000	7	14.58
High	50000-100000	24	50.00
Extremely high	>100000	15	31.26

The amounts of air conditioning energy consumption were cross tabulated against several variables related to air conditioning systems, setting, occupancy, and building including passive cooling systems as suggested by Abram[5]. These variables are air conditioning types, age of using air conditioning system, number of appliances, types of setting, numbers of worshippers, mosque shape, volume of the prayer halls, using part of the prayer hall, reducing infiltration, insulation values of mosques' envelope, exposure to the outdoor environment, allowing cross ventilation, earth contact, and water pool presence. These variables were thought to be having some relationship to the high level of air conditioning energy consumption. The result of the cross-tabulation, summarised in table 5.6, showed that age of using air conditioning system, type of setting, mosque shape and using part of the prayer hall, reducing infiltration, earth contact, water pool presence were independent variables due to their poor level of significance in relation to their Chi-square. On the other hand, it revealed that (1) air conditioning types, (2) number of appliances, (3) numbers of worshippers, (4) volume of the prayer halls, (5) insulation values of mosques' envelope, (6) exposure to the outdoor environment, and (7) allowing cross ventilation have some relation with the high level of air conditioning energy consumption where it is directly dependent upon these variables. The authors' interpretation of this relationships are discussed below.

5.4.3.1 Air conditioning type

The analysis of the levels of air conditioning energy by the air conditioning type showed a reasonable argument which may reveal the presence of a relationship. The cross-tabulation of both variables indicated that as more than one type of air conditioning system is used the level of air conditioning energy increased. The analysis

Table 5.6 The level of significance of various variables which were cross-tabulated against the level of air conditioning energy consumption

Variable	The level of air conditioning energy		
	Chi-square	Degree of freedom	Level of significance
A/C types	15.69341	9	0.07357
Age of air conditioners	13.06667	9	0.15961
Number of appliances	29.94545	9	0.00045
Setting	3.418800	3	0.33145
Number of worshippers	21.68182	9	0.00994
Mosque shape	6.449170	6	0.37480
Volume of the prayer hall	20.27583	6	0.00247
Using part of the prayer hall	1.021280	3	0.79610
Reducing infiltration	5.100000	3	0.16462
Insulation values of mosques' envelope	9.371430	3	0.02474
Exposure to the outdoor environt.	7.304350	3	0.06280
Allowing cross ventilation	9.78085	3	0.02052
Earth contact	1.02128	3	0.79610
Water pool	1.02128	3	0.79610

revealed in Table 5.7 that, among those mosques that suffered high level of air conditioning energy consumption, 75 per cent of the mosques were using more than one air conditioning system type, while only 35.7 to 53.8 per cent for those using one

Table 5.7 Cross-tabulation summary of levels of the annual air conditioning energy against types of air conditioning system.

Levels of air conditioning energy	Types of Air conditioning system			
	Window	Central	Split	Mix
Not high	25	0	7.69	0
Slightly high	25	0	19.23	0
High	50	35.7	53.8	75
Extremely high	0	64.2	19.23	25

air conditioning type. The explanation of the high percentage of mosques experiencing a high level of air conditioning energy consumption with the use of more than one air conditioning system type may be due to the different performances of the air conditioning types involved in terms of energy consumption and heat emission.

5.4.3.2 Total number of appliances

The number of appliances in each mosque and the levels of air conditioning energy consumption were cross tabulated against each other to declare the type of relationship and to provide a logical explanation for the presumed relation. The analysis of the cross tabulation of these two variables indicated that the increase in the number of appliances in the mosque was associated with the increase of the level of air conditioning energy consumption; for instance the percentage of the mosques which tended to suffer high level of air conditioning energy consumption increased among those mosques which held more appliances. This can be seen clearly between the percentages of mosques within group 3 and 4 (Table 5.8).

Table 5.8 Cross-tabulation summary of levels of the annual air conditioning energy against total number of appliances

Levels of air conditioning energy	Total number of appliances			
	up to 30	31-60	61-90	91 over
Not high	25	10	0	0
Slightly high	25	40	0	0
High	50	50	75.6	40.9
Extremely high	0	0	25	59.1

This phenomena could be interpreted as follows:

1. Since the appliances radiate heat into the prayer hall, so the more numbers of appliances in the mosque the more heat is transmitted into the prayer hall, which could increase the level of air conditioning energy consumption in the mosque.

2. The high level of air conditioning energy in the mosque may arise from the low efficiency of the cooling system, which results from the shortage in the electric current reaching the cooling system due to the high consumption of the electric appliances in the mosque.

5.4.3.3 Number of worshippers

The number of worshippers in each mosque and the level of air conditioning energy was cross tabulated. The analysis showed that the increase in the number of worshippers in mosque was associated with the increase of the level of air conditioning energy consumption. For instance, the percentage of mosques experiencing high levels of air conditioning energy increased among those mosque which could accommodate more worshippers. This can be seen clearly among the mosques suffering an extremely high air conditioning energy (Table 5.9).

Table 5.9 Cross-tabulation summary of levels of the annual air conditioning energy against total number of worshippers

Levels of air conditioning energy	Number of Worshippers			
	1	2	3	4
Not high	27.2	0	0	0
Slightly high	27.2	9.3	0	0
High	45.4	56.2	25	0
Extremely high	0	34.3	75	100

1. Up to 500 worshippers 2. 501-1000 worshippers 3. 1001-1500 worshippers 4. Over 1500

This phenomena could be interpreted as follows:

1. Since the worshippers radiate heat into the prayer hall, so the more number of worshippers attending in the prayer hall the more heat is transmitted into the prayer hall which could increase the level of air conditioning energy.
2. The high level of air conditioning energy in mosque with high level of attendance may arise from the fact that the more attendance in the mosque the more air conditioning systems are needed to satisfy their comfort and consequently the more air conditioning energy is expected.

5.4.3.4 Volume of the prayer hall

The analysis of the air conditioning energy consumption levels by the volume of the prayer hall provided a reasonable argument which may reveal the existence of their relationship. The cross-tabulation of these two variables verified that as long as the volume of the prayer hall increased, the level of air conditioning energy consumption increased accordingly. This fact could be seen in table 5.10 where the proportion of the high level to the lower level of air conditioning energy consumption was 23 to 1 in the middle size volume (2001 to 5000 cubic metres) and 2 to 1 in the small volume of prayer hall. The proportion of the extreme high level to high level of air conditioning energy was 2.3 to 1 in large prayer hall (over 5001 square metres). Two main interpretations were put forward to explain the relationship between these two variables. Firstly, the heat gain through the fabric could be higher in the large mosque with large prayer hall due to the large exposed envelope to the sun, which consequently demand more air conditioning energy consumption in the mosque.

Secondly, in the large volume mosque, there is a need to use more air conditioning systems to cool the prayer hall in short time and this would increase the level of the air conditioning energy consumption.

Table 5.10 Cross-tabulation summary of levels of the annual air conditioning energy and volume of the prayer hall

Levels of air conditioning energy	Volume of prayer halls in cubic metres		
	< 2000	2001 to 5000	5001 and over
Not high	33.33	3.1	0
Slightly high	33.33	12.5	0
High	33.3	59.3	30
Extremely high	0	25	70

5.4.3.5 The insulation values (thermal transmittance U-values) of the mosques' envelope

The high level of air conditioning energy in mosque is related to the insulation values of the mosques' envelope, i.e, the thermal transmittance U-values, due to their effect on heat gain conducted to the prayer hall. The relation between U-values of the mosque envelope and the high level of air conditioning energy consumption was defined by cross-tabulating one against the other. The analysis of this cross-tabulation revealed in table 5.11 that 83.3 per cent of the mosques using higher thermal

Table 5.11 Cross-tabulation summary of levels of the annual air conditioning energy against thermal transmittance values of the mosque envelope

Levels of air conditioning energy	Thermal Transmittance U-Values	
	High	Low
Not high	2.38	33.33
Slightly high	14.28	0
High	50	50
Extremely high	33.3	16.67

tranmittance values (U-values) experienced high level of air conditioning energy consumption, where the remaining 14.28 per cent were slightly high. On the other hand, only 66.7 per cent of the mosques using lower thermal transmittance values in the building fabric suffered high level of air conditioning energy consumption and the remaining 33.3 per cent experienced reasonable level of air conditioning energy consumption. The result showed the strong relation between the high level of air conditioning energy and the higher thermal transmittance values of the mosque fabric. The obvious explanation of the high percentage of high level of air conditioning energy among mosques having higher U-values in fabrics was as follows:

1. The use of poor building materials in the mosque fabric, which gives high thermal transmittance values, would allow more heat gain into the prayer hall and therefore results in high air conditioning energy required.

2. Due to the poor thermal performance of the building envelope the internal temperatures responded quickly to the fluctuation of the external temperature which creates uncomfortable internal environment. This would definitely encourage the use of air conditioning systems for most of the time.

5.4.3.6 Exposure to the outdoor environment

The number of surfaces exposed to the outdoor environment in each mosque and the level of air conditioning energy was cross tabulated against each other to declare the type of relationship and provide a logical explanation for the presumed relation. The analysis of the two variables revealed that the increase in the number of surfaces exposed to the outdoor environment in the mosque was associated with the increase of the level of air conditioning energy. The analysis showed that 82.6 per cent of the mosques with four vertical surfaces exposed to the outdoor environment suffered high level of air conditioning energy, while only 50 per cent of those mosque with three vertical surfaces exposed to the outdoor environment experienced high air conditioning energy consumption (Table 5.12). This phenomena can be interpreted as follows:

1. The high percentage of mosques with a high level of air conditioning energy with four vertical surfaces exposed to the outdoor environment was due to the large area exposed to direct, diffused, and reflected sun radiation which increase the heat gain conducted into the prayer hall.

2. The high level of air conditioning energy among those mosques that have less number of surfaces exposed to the outdoor environment was due to the fact that the surfaces exposed are still large in receiving direct, diffused, and reflected solar radiation which means more heat gain into the mosque and consequently demanding high level of air conditioning energy.

Table 5.12 Cross-tabulation summary of levels of the annual air conditioning energy against number of surfaces exposed to the outdoor environment.

Levels of air conditioning energy	Number of Surfaces Exposed to the Outdoor Environment	
	4	3
Not high	4.3	50
Slightly high	13.04	0
High	50	50
Extremely high	32.6	0

5.4.3.7 Allowing cross-ventilation

The survey showed that the majority of the mosques managers did not use cross-ventilation to cool their mosque, or even sufficiently exhaust the accumulated heat during the day. Cross-ventilation was cross-tabulated against the level of air conditioning energy used. The cross-tabulation of the two variables showed that 88.5 per cent of the mosques managers who did not use cross-ventilation were suffering from high to extremely high levels of air conditioning energy consumption, where only 61.53 per cent of those managers were using night cross-ventilation suffered high level of air conditioning energy consumption as well (Table 5.13). Therefore, an increase in reduction of cross-ventilation in the mosque is associated with an increase in the high level of air conditioning energy consumption. This could be explained as follows:

Table 5.13 Cross-tabulation summary of levels of the annual air conditioning energy against allowing night cross-ventilation.

Levels of air conditioning energy	Allowing Night Cross-ventilation	
	No	Yes
Not high	5.7	7.7
Slightly high	5.7	30.7
High	45.7	61.53
Extremely high	42.85	0

1. The high percentage of mosques with high air conditioning energy consumption which did not use cross-ventilation was due to the fact that the daily heat gain is trapped in the prayer hall and accumulates and therefore increasing the cooling loads and consequently demanding substantial amount of air conditioning energy.

2. The high air conditioning energy consumption among those mosques that use night cross-ventilation was due to the fact that cross-ventilation has been used for a short time and this is not sufficient to remove the heat accumulated in the prayer hall during the daytime.

5.5 The definition of passive cooling systems which need improvements

Survey and analysis are two complementary factors in any social sciences experimentation. The conducted survey specified the characteristics of the different mosque types in Jeddah region, and clarify some of the observed problems related to the quality of the mosques' thermal performance. In the light of the findings, it comes as no surprise that most of the mosques were suffering from high air conditioning energy consumption.

To have more grasp of the problem and to identify it more carefully, the mosque stock in Jeddah was categorised into three categories, each of which was defined specifically by the volume of the prayer hall. Each category was represented by two mosques; with the highest and lowest air conditioning energy consumption and the related emissions of atmospheric pollutants per cubic metres. These case studies will be studied in detail to identify the problems involved in the high level of air conditioning energy consumption.

The occupants' behaviour contributed, in one way or another, to the high air conditioning energy problem in mosque. The survey analysis indicated that the majority of the mosques in the region have some similarity concerning the cooling system used, as well as the usage time of the cooling system in the mosque. The analysis proves that most of the mosques' managers did not make enough effort to reduce the heat gain inside the mosque, or even cool it passively for more than a month. The lack of effort spent could be due to the managers insensitivity to using different ways of saving energy, such as reducing infiltration inside the prayer hall, using part of the prayer hall, and using effective passive cooling systems such as using proper building materials in the fabric so as to give lower values of thermal transmittance, reducing the exposed surfaces to the outdoor environment and allowing cross ventilation, particularly at night.

The high air conditioning energy in mosque was studied in detail to find out the associated factors. The high air conditioning energy cannot be circumscribed by only one factor, but actually are as a result of several factors. The cross-tabulation of these factors; air conditioning types, number of appliances, numbers of worshippers, volume of the prayer halls, and the adopted passive cooling systems of insulation values (thermal transmittance U-value) of the mosque envelope, exposure to the outdoor environment, and allowing cross ventilation against the level of air conditioning energy consumption, showed positive relationships on affecting the degree of suffering high air conditioning energy. It revealed that the increase in using more than one air conditioning system type, numbers of appliances, numbers of worshippers and volume of prayer hall is associated with an increase in high air conditioning energy in the mosque. Furthermore, it showed that there were deficiencies in the three passive cooling systems adopted in mosque as summarised below:

1. Using poor building materials in the envelope which gives higher thermal transmittance values.
2. Poor shading and increase of exposed surfaces to the outdoor environment.
3. Limited use of night cross-ventilation.

Finally, by reviewing the survey analysis, it could be concluded that the main problem which caused the high air conditioning energy consumption in mosque is a result of the increase of heat gain inside and the decrease of heat loss from the prayer hall. The actual increase of the heat gain inside the mosque is a consequence of two passive cooling systems. These systems, which were believed to have more effect on the heat gain, were the use of poor building materials for the fabric and the limited use of shading so as to reduce the large areas of surfaces exposed to the outdoor environment. The decrease of heat loss from the prayer hall is a result of the passive cooling system of night ventilation which has been applied for short time. Based on these findings, the necessary improvement to these passive cooling systems are suggested below:

1. Decrease the thermal transmittance U-values of the mosques' envelope.
2. Increase shading in exterior envelope.
3. Increase the use of night cross-ventilation.

In the following chapter, these passive cooling systems will be studied in detail and the proposed measures of improvements will be identified.

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CHAPTER SIX: THE PROPOSED PASSIVE COOLING IMPROVEMENT MEASURES

6.1 Introduction

So far, the different existing passive cooling systems which need improvements have been identified. In this chapter the necessary measures for improvement will be determined. In order to propose these measures, three important subjects are discussed:

1. The definition of the passive system selected.
2. The passive system principles and strategies.
3. The proposed measure of improvement.

The three subjects will be perceived mainly within the Saudi Arabian and existing mosques context.

6.2 The insulation values (U-values) of the mosques' envelope

Building envelope of existing mosques is normally composed of several layers of different building materials. This envelope acts as a barrier which controls the amount of heat entering and leaving the mosque. The flow of this heat depends of the insulation values or the thermal transmittance (U-values) of this fabric.

The thermal transmittance of a structure is defined as the amount of heat transmitted in unit time through unit area of a given structure, divided by the difference between the environmental temperature on either side of the structure and expressed by U in (W/M^2 °C). The thermal transmittance of any building element can be obtained by adding the thermal resistance of its component parts together with the adjacent air layers and taking the reciprocal of that: this procedure is given in the following formula[1];

$$U = 1 / (R_{si} + R_1 + R_2 + \dots\dots + R_a + R_{so}) \quad \dots\dots(6.1)$$

where; U is the thermal transmittance in W/M^2 °C

R_{si} is the inside surface resistance in M^2 °C/W

R_1 and R_2 thermal resistance of structural component in M^2 °C/W

R_a airspace resistance in M^2 °C/W

R_{so} outside surface resistance in M^2 °C/W

6.2.1 Principles

The building envelope represents the physical limit between the interior and exterior environment. It has to respond differently to various climatic conditions. High outdoor air temperature or solar radiation are undesirable sources of heat gain for several months in hot regions. The envelope should be able to act as a protection, as a buffer, as a filter or as a concentrator according to the outdoor conditions[2].

The actual heat low across a given building element such as wall or roof depends on the thermal conductivity of the material and the thickness of the element. The greater the thickness, the lower the rate of heat flow.

The reciprocal of this thermal resistance is termed the thermal transmittance. This determines the rate of heat flow through a given building components and is denoted by the U-value in the English system. A construction with low U-value will reduce all forms of conductive heat transfer through the building envelope[3].

6.2.2 Strategies and means

To decrease the amount of transmission gain through the building envelope three important strategies are known:

1. Increase thickness of the building element[4].
2. Use insulation[5].
3. Appropriate selection of building surfaces[6].

A. Increase thickness of the building element

Increasing the thickness of an existing building element can be achieved by adding building materials available in the local market. Three building materials are commonly found in Saudi Arabia and can be used for this purpose. These are calcium silicate blocks for walls, plaster board for walls and roofs and cork board for roofs. Each of these materials will be discussed individually.

1. Calcium silicate blocks:

Calcium silicate products are building materials and were invented in 1866 in Great Britain[7]. Many industries were established in many countries all over the world among which were most of the Middle East Countries. During the early seventies calcium silicate products factories were established in Saudi Arabia in major cities such as Dammam and Jeddah to supply the building development with the needed materials. The main products of calcium silicate are[8]

1. Brick, blocks and tiles with the specification of British Standards 187.
2. Bricks and blocks of the American National Standard A821 and A781.

Calcium silicate products are of different colours and sizes. The produce can be used in internal and external walls (as load bearing or non-load bearing). They can be used in domestic, industrial and commercial buildings but they must not be exposed to acids or to strong salt solution. It is made of 90% sand and 10% quicklime drawn from local sources. These products offer considerable advantages in construction and finishes. Moreover, the products have a good values of sound and heat transmittance through walls[9]. Based on these properties, the products can also be used in existing buildings.

2. Gypsum plaster board

Gypsum in large deposits of various grades are indigenously available in some developing countries. This material is commonly used in preparation of plasters and the production of cement. It is also used to produce/make to obtain gypsum plaster, which is used for internal decorative work. Fibrous gypsum plaster board reinforced with jute, reeds, glass, wood galvanised wire mesh or other materials is used for floors, ceilings, and light partition. The manufacture of this product could be undertaken on a cottage industry basis[10]. This is the case in Jeddah.

Gypsum plaster board consists of a core of set gypsum enclosed between, and firmly bonded to, two stout lining papers. It is manufactured to the BS 1230, which includes the following main types:

1. Gypsum wall board.
2. Gypsum base wall board.
3. Gypsum moisture resistant wall board.
4. Gypsum repellent wall board.
5. Gypsum base board.
6. Gypsum wall board F (fire performance).
7. Gypsum base board F (fire performance).

Gypsum plaster board is usually fixed by nailing to wood joints or studs, or metal studs which are at 400, 450 or 600 mm centres. It is obtained in thickness of 9.5, 12.5, 15, and 19 mm with width from 406 to 1200 mm. The length varies from 1200 to 3000 mm according to the purpose and type of board used[11]. Gypsum plaster board with the specifications mentioned above are found in Saudi Arabia. The common plaster board is the fibrous one which is discussed above and mainly used for decorative purposes. The panel is either 500x500 or 500x600 mm with a thickness of 15 mm. Plaster boards are commonly used for walls and decorating the ceilings and has a density of 950 kg/m^3 and a conductivity of 0.16 W/mk[12].

3. Cork board:

Cork board is a type of insulation in a form of board used in flat roofs: built up asphalt, inverted[13]. Cork as a material is light and a good insulator of heat and sound. Its structure and properties resemble polystyrene foam[14]. Cork board has a density of 145 kg/m and a conductivity value of 0.042 W/mk[15]. Cork board is commonly used for covering the ceiling in Saudi Arabia. Nowadays, these boards are produced locally, but substantial amounts are still imported from abroad. These panel boards are found in different sizes, the most common sizes used are 300x300mm and 300x600mm.

4. Glass

Glass has been used widely in building over the last few decades. Due to its thermal behaviour, it contributes substantially to passive solar house design. Glass has the ability to allow the short-wave radiation coming from the sun and opaque the long-wave radiation coming from the low temperature. This process is known as the greenhouse effect[16]. The requirements of window glass vary from hot regions to cold ones. In hot regions it is used to provide daylight with the minimum heat gain and view. While in cold regions it is used to provide light, solar radiation and view.

At the present, various types of glass with different thermal properties have been developed and produced. Their variation is based on the degree of their transmission, reflection and absorption of heat. In general, all types of glass have the ability to absorb and reflect solar radiation. Heat-absorbing glass tends to absorb heat more, whereas heat-reflecting glass reflects more infra-red radiation than ordinary glass. The heat reflective glass, possessing a very fine semi-transparent metallic coating, reflects a large portion of the infra-red radiation. This reflective coating is protected by double glazing, or by a mesh screen. On the contrary, the heat absorbing glass breaks down the solar heat gain through that glass into two parts; (1) the transmission of short-wave visible light and infra-red radiation and the (2) the inward heat flow by convection and long-wave radiation from the heated glass surface.

B. Insulation materials:

Thermal insulation can be defined as "a material or assembly of materials used primarily to provide resistance to heat flow"[17]. These insulation materials are therefore an essential tool in minimising the heat passing through the external envelope of the building. The main benefits when using these materials in the building are (i) improving the living situation and (ii) reducing the energy consumption.

Lately, various types of insulation materials have been introduced in Saudi Arabia. More than 20 factories are now producing different types of insulation materials in the country. These insulation materials are classified into four categories as follows;

1. Rigid insulation: is a fibre board material in sheet or other forms which is made of some inorganic fibre such as wood, sugar cane or other vegetable products. It can be found as (i) foamed polystyrene and urethane plastics used in roof, walls, and grounds (very light in weight and durable in strength) and (ii) fabricated board which may be used as wall board and roof decking.
2. Flexible insulation: is composed of felted mats of mineral or vegetable fibres, cotton, and wood fibre.

3. Reflective insulation: is extremely high reflective material produced in the form of aluminium foil, sheet metal with thin coating, and paper products coated with a reflective oxide composition. This type of insulation can be harmful to the environment as it may reflects the heat back to the streets, adjacent buildings and the passing people.
4. Loose fill insulation: is made of rock or glass products. It is available in bags and used conveniently in the walls of the hollow concrete blocks existing buildings which were not originally insulated.

The thermal conductivity of the various insulation materials described above is shown in table 6.1.

Table 6.1 The thermal conductivity of some insulation materials

Insulation Group	Specific Insulation Type	Range of conductivity
Flexible fill	1. Standard material	0.25 - 0.27
	2. Vermiculite	0.28 - 0.30
		0.45 - 0.48
Rigid	1. Insulating fibre board	0.35 - 0.36
	2. Sheathing fibre board	0.42 - 0.55
Foam	1. Polystyrene	0.25 - 0.29
	2. Urethane	0.15 - 0.17
Wood		0.60 - 0.65

Source: Housing Science, Vol. 7, no. 3, 1983, p. 229

5. Air cavities can be used as a good insulator for walls and roofs; air cavity walls and air cavity roof. For existing walls, air cavity walls can be added easily while for existing roof an alternative suspended ceiling can be applied using the same concept. The thermal resistance of air cavity will be discussed in details in Chapter

Seven.

a. Cavity roof and suspended ceilings

Suspended ceilings are used for five purposes[18]. These are as follows:

1. For visual reasons.
2. To reduce heights.
3. To upgrade fire resistance.
4. To conceal services, particularly the frame and tile type.
5. For heat resistance.

They are made up of distinct elements:

1. The suspension system.
2. The panels (infill panels).
3. The service elements, such as lights and air conditioning diffusers.

Suspended ceilings are categorised as follows:

1. Jointless systems.
2. Frame and tile systems.
3. Service-integrated frame and tile system.
4. Linear strip systems.
5. Louver/open grid systems.

The frame and tile systems is the most commonly used type of suspended ceiling. Tiles or planks are laid into the framework suspended from the structural ceiling above. Connections to adjacent surfaces are simple as the suspension members and tiles can be cut to the length required. Materials and finishes for tiles or panels are many and various, including mineral fibre tile, metal lay-in trays, three dimensional panels, and open gridded tiles. The common sizes of the tiles are 300x300 or 600x600 mm and the planks are frequently 300x1200 or 300x1500 mm.

The common features of these products are as follows:

1. Acoustic.	2. Decorative.	3. Illuminated.
4. Fire resistant.	5. Moisture resistant.	6. Thermal insulated.

Panels and tiles of the suspended ceilings are made of various materials. The most common types available in the Saudi market are:

1. Aluminium panel.	2. Stainless steel panel.	3. Fibre board.
4. Wood particle board.	5. Cork board.	6. Gypsum plaster board.

Each one has a different level of emboded energy (manufacture and installation).

C. Building surfaces

Surfaces should have a maximum reflectivity in the short wave region of the spectrum to reflect solar radiation and a maximum emissivity in the long wave region to favour night radiation. High reflectance of vertical surfaces in urban sites may contribute to an increase in solar input for adjacent buildings and may enhance daylight for other buildings. Night radiation from vertical surfaces is limited, however, floor surfaces radiate intensively and interact less with other buildings[19].

6.2.3 The proposed measures of improvement

The materials used in constructing existing air conditioned mosques have the property of conducting heat or cold into or out from the prayer hall. These materials have some insulation values, which are not, however, effective to the extent desired for a comfortable internal environment. There is an inflow of heat through these walls and roofs in hot weather which consequently affects the amount of air conditioning energy. Therefore, the use of building and insulation materials in this building is an important factor to reduce the air conditioning energy, money and the related emissions of CO_2 and CFCs. Furthermore, both building and insulation materials have the capability of maintaining cool conditions in side the mosque for a longer duration.

The building materials' market supplies the world with many types of insulation materials, which have different insulating properties. The availability of many varieties of building and insulation materials puts the builder and the client in an uncertain situation when choosing the proper insulation materials for adequate savings in air conditioning energy, money, CO_2 emissions, and CFCs emissions. The improper selection of building and insulation materials may drive the user of the mosque to use more air conditioning energy as well as more emissions of CO_2 and CFCs. Therefore, various types and thickness of building and insulation materials were proposed for existing walls and roof of air conditioned mosques.

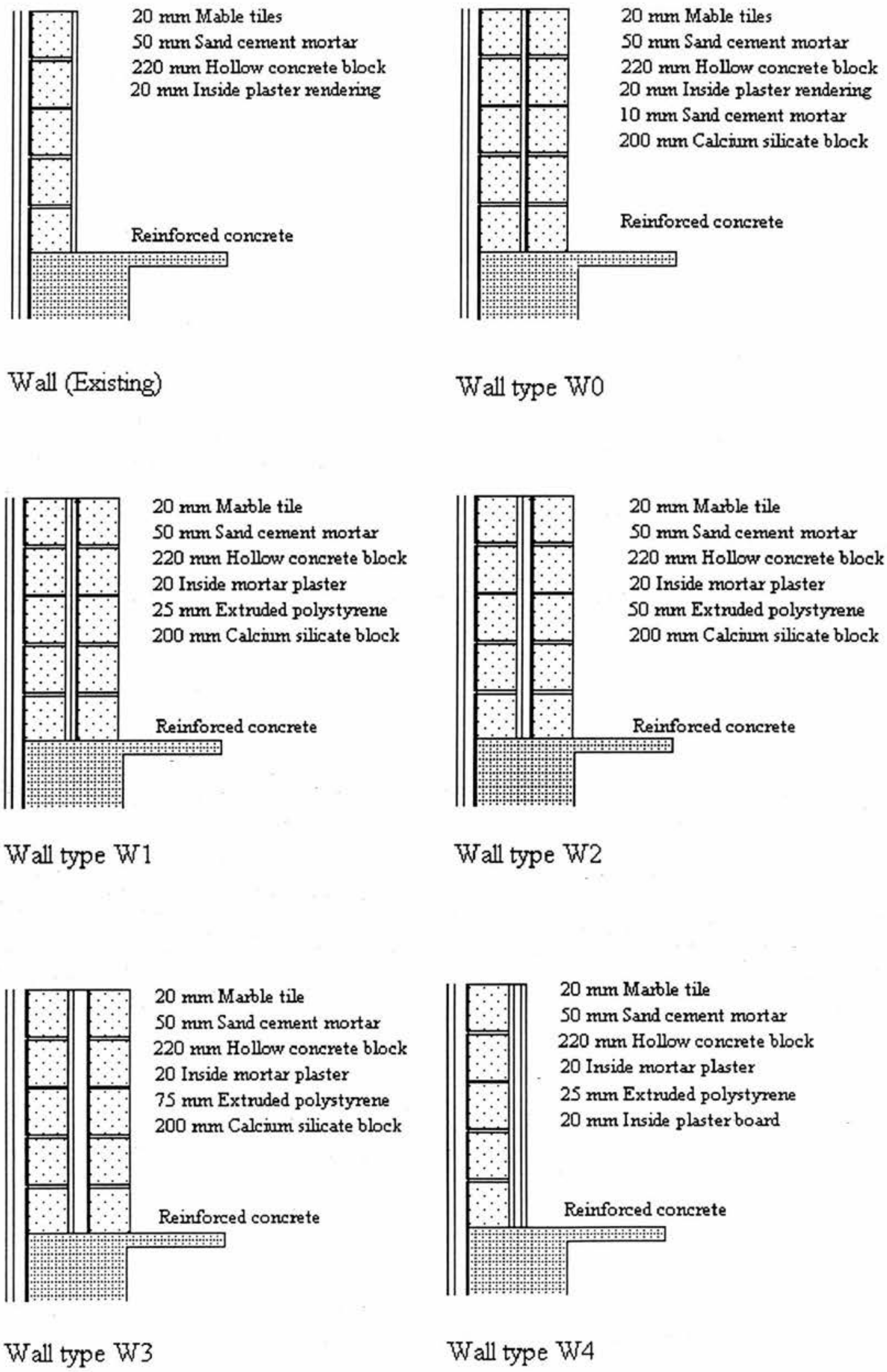
The proposed improvement measure of increasing insulation values of walls and roofs by adding building and insulation materials will be placed from the mosque interior. These building and insulation materials are easy to erect, does not require too much space and does not demand heavy structural support to rely on, and are available in the local market. Moreover, the additions of these materials will have no effect on the expensive marble facades. On the other hand, the addition of glazing to existing windows cannot be carried out due to the fact that the current frames are designed only to fit the 6 mm glazing used. It is suggested to add calcium silicate blocks for existing walls and a gypsum suspended ceiling for roof.

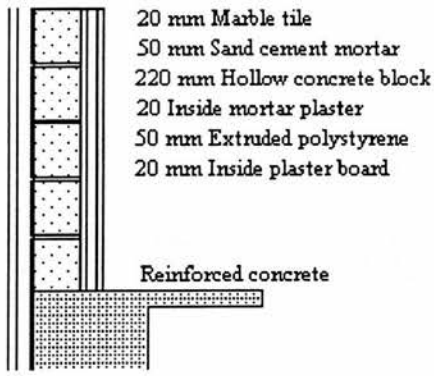
6.2.3.1 The proposed building and insulation materials for existing walls

Being exposed to the sun, exterior wall is heated during the day and loses some of this heat at night. The thermophysical properties of the wall determine the heat gain through the wall where they absorb and reflect some of the heat and the remainder passes to the interior.

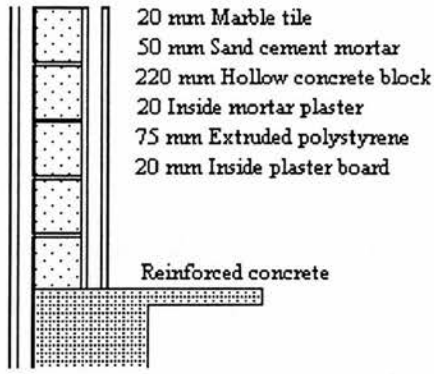
The composition of the different proposals for adding different local building and insulation materials to existing walls are described more specifically in figure 6.1, where eight different compositions of building and insulation materials are proposed for existing wall. The most common existing type in Jeddah's mosques is the 220 mm hollow concrete block with 20 mm outside marble tile and 20 mm plaster internal surface; followed by the first proposal of using the 200 mm calcium silicate block (W0). The second, third and fourth proposals (W1, W2 & W3) consists of various

Figure 6.1 Detailed drawings of the various building and insulation materials proposed for existing walls.

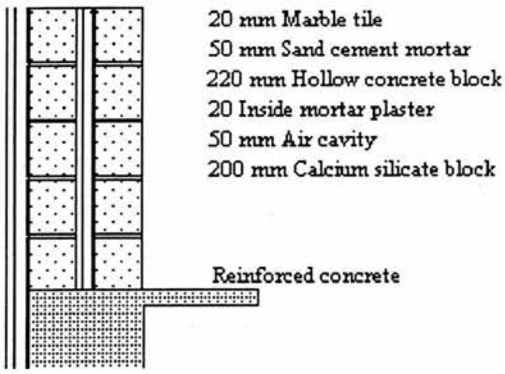




Wall type W5



Wall type W6



Wall type W7

thicknesses of extruded polystyrene of 25 mm, 50 mm, and 75 mm with the use of 200 mm calcium silicate blocks. The fourth, fifth and sixth proposals W4, W5, W6 are composed of various thickness of insulation material similar to W1, W2, W3 covered with plaster board. The last proposal is consisting of 50 mm air cavity with 200 mm calcium silicate block (W7).

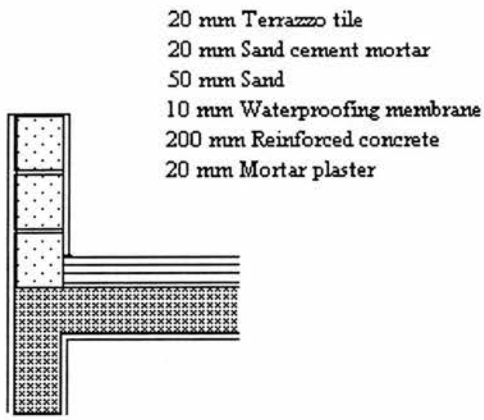
6.2.3.2 The proposed building and insulation materials for existing roof

Building is normally affected by the climate. The roof, however, is the building element most subjected to solar radiation (direct and diffuse) all day long. When compared with a wall, the roof receives a great deal of solar radiation because it is a horizontal plane. Roofs gain heat during daytime and lose most of it during the night (longwave radiation). The external surface of the roof absorbs heat which is transferred to the internal environment by conduction. Thus thermal conductivity of roof components will determine the amount of heat gain and loss through the roof.

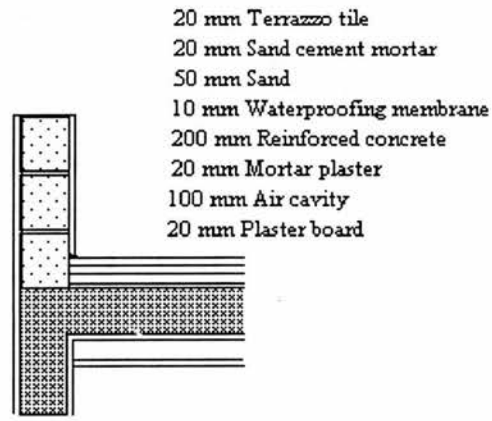
Most existing mosques use single skin reinforced concrete. The various types of proposed building and insulation materials which can be used in the ceiling of existing roofs are described in detail in figure 6.2, defining eight types of composition of building and insulation materials and specifying their thickness, their thermal conductivity, resistance and thermal transmittance.

The different ceilings types described in the table starts with the most common type used in the region which is composed of 200 mm reinforced concrete covered

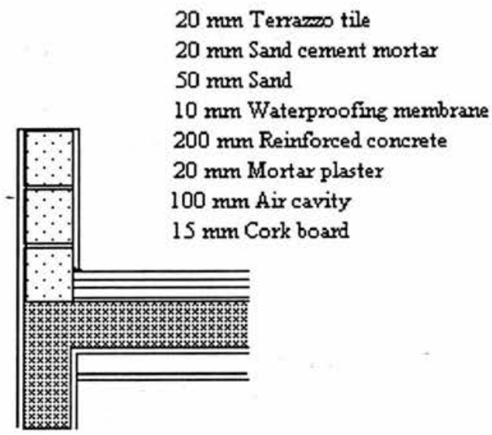
Figure 6.2 Detailed drawings of the various composition of the roof with different proposed ceiling types.



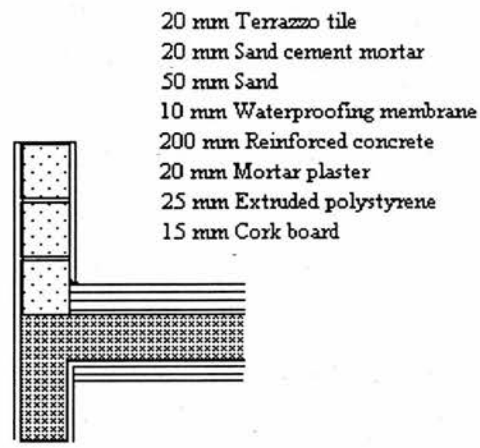
Ceiling (Existing)



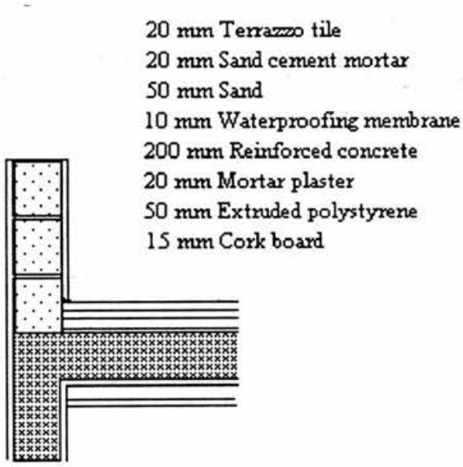
Ceiling type R0



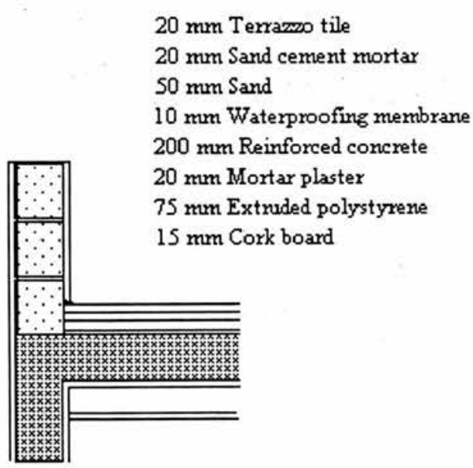
Ceiling type R1



Ceiling Type R2

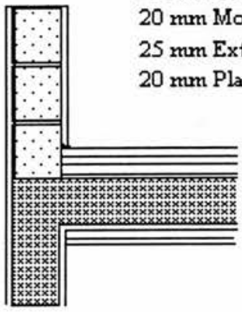


Ceiling type R3



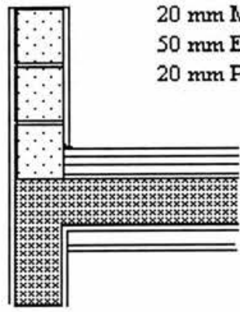
Ceiling type R4

20 mm Terrazzo tile
20 mm Sand cement mortar
50 mm Sand
10 mm Waterproofing membrane
200 mm Reinforced concrete
20 mm Mortar plaster
25 mm Extruded polystyrene
20 mm Plaster board



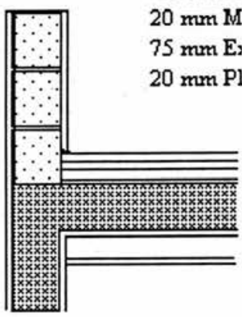
Ceiling type R5

20 mm Terrazzo tile
20 mm Sand cement mortar
50 mm Sand
10 mm Waterproofing membrane
200 mm Reinforced concrete
20 mm Mortar plaster
50 mm Extruded polystyrene
20 mm Plaster board



Ceiling type R6

20 mm Terrazzo tile
20 mm Sand cement mortar
50 mm Sand
10 mm Waterproofing membrane
200 mm Reinforced concrete
20 mm Mortar plaster
75 mm Extruded polystyrene
20 mm Plaster board



Ceiling type R7

with mortar plaster, and is followed by the first two ceiling types consisting of 100 mm air cavity with 20 mm plaster board (C0) and 15 mm cork board (C!) respectively. The three ceiling types of C2, C3 and C4 have insulation materials of 25 mm, 50 mm, and 75 mm of extruded polystyrene covered with cork board. The last three proposed ceiling types of C5, C6 and C7 are similar to C2, C3 and C4 but use plaster board as a finish material.

6.2.3.3 Combination of improved existing walls and roofs

Different combinations of modified walls and roofs by adding various building and insulation materials proposed before will be investigated.

6.3 Shading

6.3.1 Principles

Elimination of the direct beam and part of the diffuse component of the irradiance directed toward a surface, by obstruction along pre-selected parts of the daily and annual sunpath.

6.3.2 Strategies and means

Three main means of shading are known[20]:

1. Site topography and layout.
2. Building form.
3. Aperture components encompassing fixed and adjustable/retractable shading devices, internal blinds or shutters and combinations.

Shading related to site conditions

Overshadowing of building or part of it from site obstruction and adjacent buildings is very important in reducing substantial amounts of direct solar gain falling on it. Close spacing could be desirable. Trees and vegetation have great potential in shading outdoor spaces or for building facades.

Shading as related to building form:

There are many solutions in the hand of the architects as far as the solar control in building is concerned. These are as follows:

1. Manipulation of the roof in shape and properties
2. The control of exposure of selected orientations and an overall surface-to-volume ratio
3. Through plan form and sectional arrangement as means of protecting certain surfaces or spaces at certain periods.
4. The extension of the plan in the form of balconies, courtyards and other semi-outdoor spaces that can play the dual role of shading device and useable space

Shading as related to aperture

The ingress of solar radiation contributes to discomfort especially in the tropical hot climate where the ambient temperature are always within or above the comfort zone. Solar radiation entering a prayer hall can have the following effects:

1. Radiation absorbed on to room surfaces will lead to increase the air

temperature, and mean radiant temperature.

2. High intensities of both direct and diffuse radiation can cause discomfort glare affecting the occupant visual performance
3. Solar radiation falling directly on to an occupant will lead to an increase in the mean radiant temperature experienced

The function of shading is to eliminate these three effects. In the mean time, shading itself is subjected to other constraints

1. A necessity for view through windows.
2. Admission of controlled levels of diffused daylight.
3. Maintaining air flow through the building via openings.

One or a number of shading devices can be employed. The devices are of three types as follows:

1. Movable opaque, e.g. roller blind, curtain, etc. Although it eliminates view and impedes air movement it is very effective in reducing solar gains.
2. Louvers provide security and affecting the view and air movement to some degree. These louvers are either fixed or adjustable.
3. Fixed overhangs, have little effect or no effect on views and air movement. Easy to attain on single storey buildings with overhang roof. In addition, it gives protection to walls and openings from rain.

Curtains or movable blind

It is of greater benefit in using light colour fabric in curtains so that more radiant energy will be reflected back out of the building. Many light coloured fabrics also transmit a substantial amounts of radiation. Normally dark colour has the ability to absorb rather than reflect and consequently will generate heat inside the building.

In air conditioned buildings, an opaque or translucent blind can be used to reduce glare, effects of direct radiation on users, and cooling load. On the other hand, in non-air conditioned buildings these blinds have limited application since they impede air flow.

Fabrics with aluminiumised finishes on one side are now available and are very popular. These are highly opaque but still look light coloured when illuminated from inside. A reflective plastic films could also be used as an alternative. These could be integrated with the glazing and could be even replaced by reflective glass. Unfortunately, all of these measures tend to redirect solar radiation in such a way that they increase glare to external spaces.

Geometric shading- overhangs and louvers

The traditional method of shading in most places of the tropics is by the use of fixed overhangs accompanied with the careful consideration for orientation. With the preferred orientation of the building along axis E-W, the roof provides sufficient overhang to protect the entire north and south wall.

Louvers are actually designed to divide the window into a number of wide but very low windows, each with its own overhang. Vertical shadings (fins) are better for shading facades of more than 45 from N-S, while horizontal overhangs are suitable for shading N and S facades. A combination of both vertical and horizontal projections are sometimes used. A number of geometric shading devices are shown by Evans (fig. 6.3).

6.3.3 The proposed measure

Increase shading for existing windows by using the highly effective shading device. This shading device is available in the market, easy to erect and will keep the current marble facades unaffected. While the increase of shading of existing walls and roofs may require the use of rigid elements capable of providing perfect shading with high resistant against the harsh climatic conditions of high temperature and high humidity. These rigid elements such as *Riwaq* walls (additional wall located at least 2 to 3 metres away from the existing walls) or double roof require structural support which most existing air conditioned mosques cannot provide. In addition, these shading elements demand space around the mosque which may not be available for all mosques. Plants are not effective for proper shading as far as the diffused and reflected solar radiation are concerned. Moreover, plants need water which is not available in the region in large quantities and they are not effective as a short term solution. It is suggested to use the effective shading device, of 45° incline tested by Evans for existing windows.

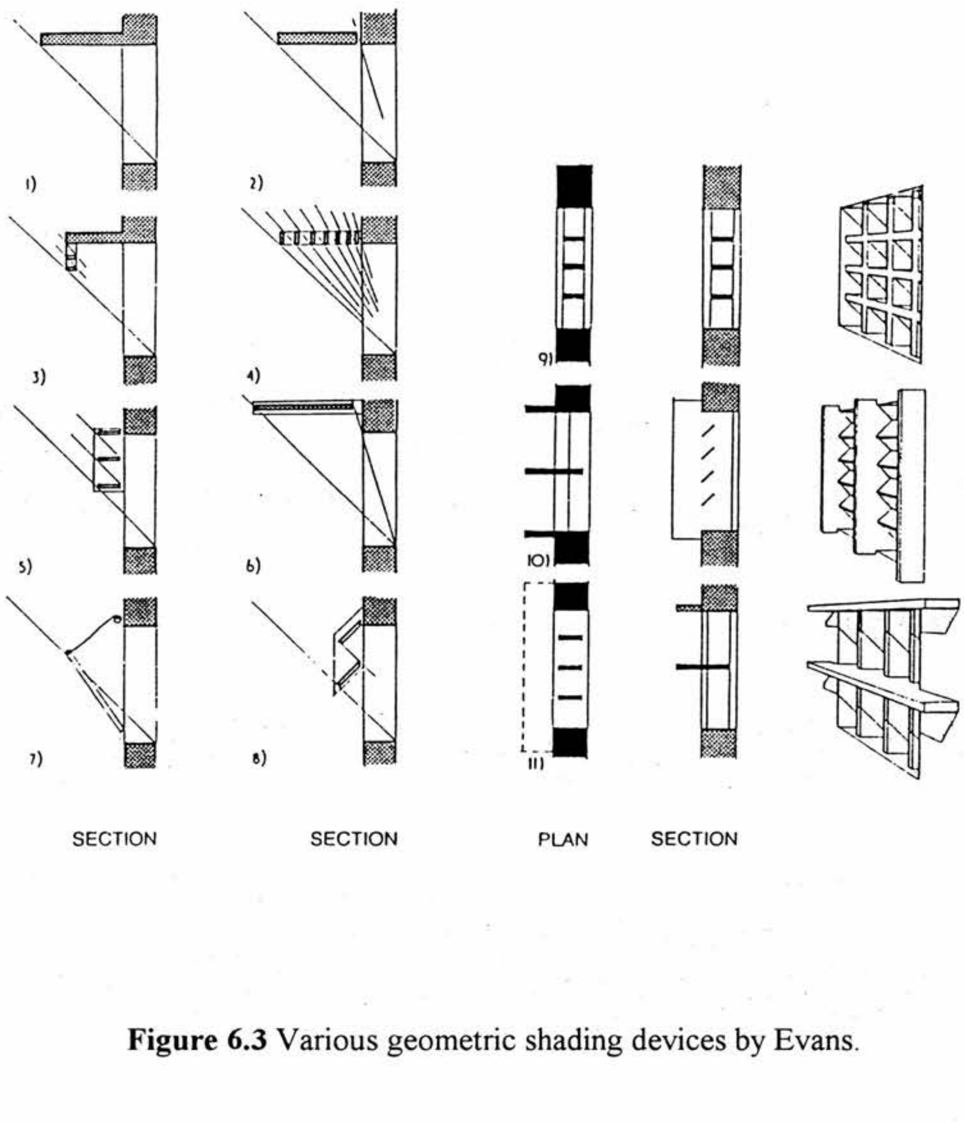


Figure 6.3 Various geometric shading devices by Evans.

6.4 Night ventilation

Ventilation provides cooling by using air to carry heat away from the building and/or from human body itself. Air movement may be created either by natural forces (wind and stack effect) or mechanical power such as fans. Air flow patterns are the result of differences in the pressure distribution around and within the building. Air moves from high pressure regions to low pressure ones.

Night ventilation may offer a higher potential for building cooling due to the lower outside temperature[21]. If the temperature outside the building is lower than the inside, flushing the building with the cool air over the night is possible to exhaust internal heat gains or solar gains during the day.

6.4.1 Principles

With a diurnal temperature fluctuation of 6-10 °C, coolth storage in structural mass is worth considering particularly for those buildings normally unoccupied at night. Mosque buildings are always left unoccupied at night (between Isha'a and Fajr prayers)

A study of a heavyweight structure in the climate of Darwin, North Australia reveals the beneficial effects of mass with night ventilation (fig. 6.4). The results have been achieved with the use of computer simulation. The curves shows that the

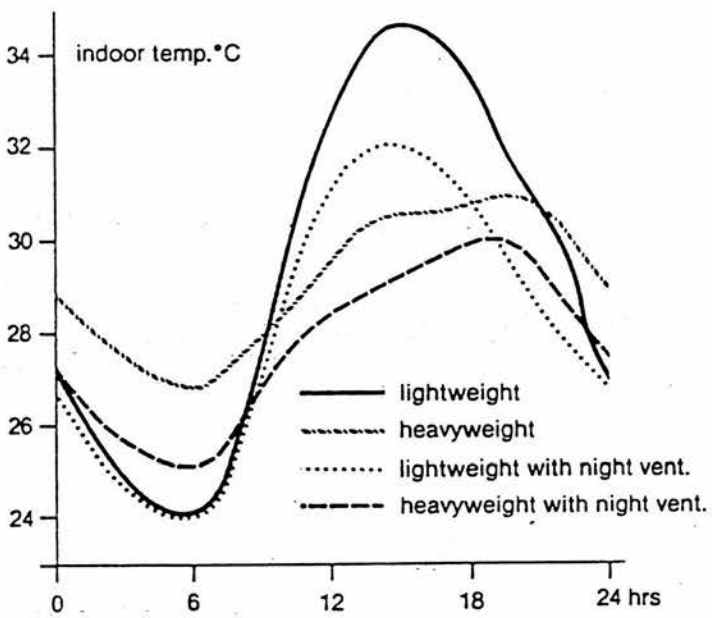


Figure 6.4 The result of a study of a heavyweight structure in the climate of Darwin, North Australia shows the benefit of night ventilation.

heavyweight structure is considerably warmer at night while during the day reveals a 2 °C reduction in peak temperature. This performance is enhanced if the day time ventilation rate is decreased to 1 air change per hour and the night time ventilation is increased to 30 ac/h; peak day temperature is almost 4°C lower than the lightweight structure whereas night temperature is only about 1°C above the lightweight case.

The results look encouraging, but with limiting the ventilation to 1 ac/h in the day time this will make a radical difference to the thermal behaviour of the building. Moreover, as a result of this reduction in ventilation during day time, the building will be much more sensitive to internal gains of any kind and much care has to be taken with other measures such as shading, etc.

Finally, when limiting the daytime ventilation to a lower level (1 ac/h), it means that all physiological cooling effect connected to natural air movement will be diminished. Air movement is likely to be necessary due to the fact that depression of temperatures will not be enough to remove the need to rely on evaporative loss. This air movement will have to be provided by fans.

6.4.2 Driving forces of natural ventilation

A. Wind Effect

When the wind strikes a building, a positive high pressure zone is created; windward facade. The air surrounds the building and eddies develop on the side and leeward facade inducing a low pressure region. In the presence of open windows, door and shaft as a connecting path between high and low pressure zones, cross ventilation will be induced. Both air flow resistance and pressure difference determine the mass flow rate and the air velocity within the occupied space.

B. Stack Effect

Temperature difference induces a density difference and according to the physical principles, light air tends to move to a higher position if possible. Air movement is therefore established due to the so-called buoyancy forces. Ventilation through buoyancy needs both (i) a significant temperature differential and (ii) a low building's internal vertical resistance to air movement. Stack effect and wind effect can act separately or together. In most cases buoyancy forces are dominated by wind if blowing.

6.4.3 Strategies and means

Several strategies can be adopted to take benefit of the driving forces of natural ventilation.

1. Solar Chimney:

The sun is normally used to warm up an internal surface of the chimney creating a temperature difference and consequently developing buoyancy forces inducing an upward flow along the plate, The chimney may serve as a stair well and be completely integrated in the building architecture. Moreover, the chimney width should be closed to the boundary layer width in order to avoid potential backward flow[22].

2. Wind Tower:

Wind towers draw upon the driving forces of the wind to generate air movement within the building[23]. The wind-scoop inlet of the tower as oriented toward the windward catches the wind and drives the air down the chimney. The air exits through a leeward openings after being travelled inside the building. Alternatively, the chimney cap can be designed to create a low pressure region at the top of the tower, and the suction initiated airflow up the chimney. A windward opening should be associated with the system for air inlet. The process in this case will benefit from the buoyancy of the warm inside air.

3. Openings: Distribution and Shape[24,25]:

The distribution of the openings on building facades is a key element for efficient natural ventilation. The position of the inlet dominates the air flow pattern within the spaces. The position of the outlet is of secondary importance.

Single sided ventilation is considered to be an inefficient strategy; cross ventilation is preferred. With the use of openings parallel to the wind no significant movement of air occurs within the occupied space. On the contrary, if the wind is oblique to the openings, the flow circulates in the entire space. It is possible to further enhance cross ventilation if two outlets are placed on the building side walls.

High inlets do not generate a strong air velocity in the occupied zone. They are often used for night ventilation as the air stream is directed toward the storage element. Placing the openings at human body height is considered to be most effective for body cooling.

Roof openings or clerestories may be used to encourage anabatic flow when the building is too deep to offer cross ventilation or the opposing openings are not possible. The roof opening should be designed to create a low pressure region next to the opening so as to enhance the natural stack effect.

4. Building Shape:

Ventilation of a space with one opening can be improved if two openings are placed on the facade as far apart as possible. Wind fluctuations generate pressure differences between the two windows and consequently induce air circulation all over the space. Furthermore, placing wing walls for the windward windows can enhance the pressure differences between the two windows and induce air circulation and increase cross ventilation in the room. Finally, vegetation can also affect the air flow pattern in the same way as outside buildings or wing walls[26].

5. Window Selection:

The window should be as large as possible to optimise cross ventilation. However, a compromise has to be realised between daylight, solar gain, operation, cost and air movement control. Horizontally shaped windows should be preferred to vertically ones as they induce a higher air velocity within the occupied zone[27]. Table 6.2 illustrates the main characteristics of the various window styles as far as ventilation is concerned.

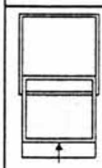
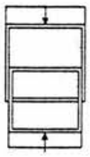
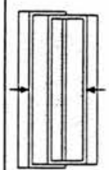
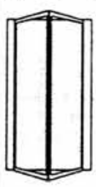
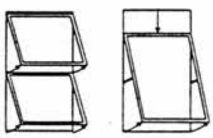
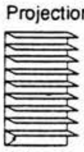
6. Limits:

Wind induced ventilation would be an ideal strategy if winds were steady in direction and intensity. Unfortunately, winds are extremely variable and weather data not available at most sites. Tracking the wind systems are difficult to realise. Taking advantage of prevailing winds in a complex changing environment is considered to be a difficult exercise in a multidisciplinary design. No major tool can bring a clear answer to the designer.

Higher air change rates should be achieved in order to maximise the cooling benefits of ventilation. If night-time temperature remains above the interior temperature, night-time ventilation tends to be a problem rather than a help.

Buoyancy driven ventilation can represent a secondary technique but its effect are more limited in time and in intensity. Stack effect may exhaust a substantial amount of heat in a short time but has a very limited effect in summer conditions. In these situations, forced ventilation can be used to extend the opportunities of using ventilation cooling.

Table 6.2 The main characteristics of the various window styles with their ventilation potential

Window type	Advantage	Drawback
 Single Hung	Adjustment of the opening area. Air enters the openings and continues inside in the same direction as the outside wind.	Opening limited to 50 % of the window size. Winter leakage.
 Double Hung	Adjustment of the opening area. Adjustment of the sashes for directing air streams to a specific area.	Opening limited to 50 % of the window size. Winter leakage.
 Horizontal sliding	Adjustment of the opening area to direct air streams to a specific area.	Opening limited to 50 % of window size. Width/height small ratio does not favor hight efficiency for every wind direction.
 Side hunged	100 % openable. Sash can act as a wingwall and redirect the flow. Good sealing.	Difficult window treatment. Low market penetration
 Projection and awning	Excellent rain protection.	At low opening angles, the airflow is deflected upward, outside the occupied zone. Reduced opening area
 Jalousie	Take benefit of all wind direction. 100 % openable. Can direct The flow.	Excessive infiltration
 Basement and Hopper	Excellent for night ventilation and for air intake and exhaust. Can stay opened.	Reduced opening.

7. Mechanical Fans:

A ceiling fan, an oscillating fan and a box fan can be used to supplement the weakness of natural ventilation through increasing the interior air velocities and convection exchange. Fan has the capability of restoring summer comfort within the building outside the typical comfort zones. This capability has been proven by Wu et. al[28] and the results are shown in table 6.3.

6.4.4 The proposed measure

Increase night ventilation rate by leaving existing windows open at night for long hours and without the use of fans. Windows in existing mosques are abundant and can be found in most of the mosques' walls. Moreover, mosques are never used between Isha'a and Fajr prayers. Fans are not available in all existing mosques. It is suggested that the mosques windows should be left opened for 7 hours.

Summary

The definition of existing passive cooling systems and the various methods which can be used for improving these systems have been highlighted. These systems are the insulation values of the mosques' envelope, shading and night ventilation. The proposed measures for improvements are as follows;

1. Increase insulation values of walls and roofs by adding building and insulation materials from interior.
2. Complete shading for existing windows by using the highly effective shading device made of aluminium.

Table 6.3 Fan types and its capability of restore summer comfort within the building outside the typical comfort zones.

Fans	Dry Bulb	Relative Humidity	Air Velocity
Ceiling	27.7 °C	73%	1.02 m/s
	29.6 °C	50%	1.02 m/s
	31 °C	39%	1.02 m/s
Oscillating	31 °C	50%	1.52 m/s
	32 °C	39%	1.52 m/s
	33 °C	30%	1.52 m/s

3. Increase night ventilation rate by leaving existing windows open at night for long hours and without the use of fans.

So far, both the passive cooling strategy and the passive cooling improvement measures for existing mosques have been determined. In the following chapter the discussion will be devoted to the development of the potential savings calculation methods from the proposed strategy and the measures of improvement.

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CHAPTER SEVEN: CALCULATION METHODS FOR PREDICTING SAVINGS IN AIR CONDITIONING ENERGY CONSUMPTION, MONEY AND CO_2 AND CFCS EMISSIONS AS RELATED TO THE PROPOSED PASSIVE COOLING STRATEGY AND THE IMPROVEMENT MEASURES

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CHAPTER SEVEN: CALCULATION METHODS FOR PREDICTING SAVINGS IN AIR CONDITIONING ENERGY CONSUMPTION, MONEY AND CO_2 AND CFCS EMISSIONS AS RELATED TO THE PROPOSED PASSIVE COOLING STRATEGY AND THE IMPROVEMENT MEASURES

7.0 Introduction

In the previous chapters, the passive cooling strategy and the passive cooling improvement measures have been defined. In this chapter, the intention is to develop calculation methods able to predict the performance of both the strategy and the improvement measures. This performance is primarily related to air conditioning energy consumption, money and atmospheric pollutants emissions reductions.

7.1 Calculation of reductions in air conditioning energy consumption due to the proposed passive cooling strategy

In calculating the amount of air conditioning energy savings due to the proposed strategy, the method is to sum all the air conditioning energy amounts consumed during the periods where this strategy is applicable. This period is found to be the whole months of the year except June, July, August and September for Duhur prayer and the last 10 days of June and whole months of July and August for Asr prayer. The following equation has been adapted:

Air conditioning energy saved = Current annual a/c energy consumption - a/c energy consumption for Duhur (June, July, August and September) and Asr prayer (last 10 days of June, July and August).

7.2 Calculation of reductions in air conditioning energy consumption due to the proposed passive cooling improvement measures

There are numbers of tools available for use in passive cooling calculation. Best known are ESP, OASIS and BLAST. The majority of these tools are expensive and require tremendous amounts of data input which are not available on a long term basis in almost all developing countries. Manual methods using limited available data are therefore preferable.

The calculation method used for the improvement measures performance is a modified version of the Passive Cooling Evaluation method (PACE) developed by Dr. Nick Baker of Cambridge University. It is a manual calculation method able to calculate the energy saving due to the adoption of passive measures. Where passive measures are used to reduce air conditioning energy, the saving are calculated by summing the monthly reductions in heat gain under the following categories:

1 Solar external gain.

2. Internal solar gain.

3. Conductive gain.

4. Ventilation gain.

5. Lighting gain.

6. Other casual gains.

7. Night ventilation.

The general method of PACE and the method adopted and modified in this research is revealed in Table 7.1.

The contributions of the proposed measures as related to U-values of the fabric, shading and night ventilation to the amounts of heat gains in the building and heat loss from the building are as follows:

1. U-values and shading as related to walls and roof are strongly connected to external solar gains.
2. U-values and shading as related to windows have a relationship with the internal solar gains.
3. U-values as related to walls, roof and windows will have a major link with

Table 7.1 PACE and the research method of calculations

PACE	This Research
A. Cooling load reductions	A.. Cooling load reductions
1. Solar external gain	1. Solar external gain
2. Internal solar gain.	2. Internal solar gain.
3. Conductive gain	3. Conductive gain
4. Ventilation gain	7. Night ventilation
5. Lighting gain	
6. Other casual gains	
7. Night ventilation	
B. Correction factors and useful reductions	B. Correction factors and useful reductions
C. Air conditioning energy reductions	C. Air conditioning energy reductions
	D. CO_2 emissions reductions
	E. CFCs emissions reductions
	F. Money saved
	G. Payback period

conductive gains.

4. The night ventilation rate has a strong connection with heat loss from the building.

Each of three passive cooling systems' contribution will be discussed in detail in the following sections. The discussion will address the important issues of how and by how much the heat gains and loss can be changed due to:

1. Change in U-values of the building fabrics.
2. Change in shading.
3. Change in night ventilation rate.

7.2.1 General characteristics of the calculation method and the general equation

The evaluation method is characterised by the following factors:

. Offers a manual calculation (calculator and pencil) method.

. To calculate the effect of passive cooling measures in energy and environment concerning the emissions of CO_2 and CFCs.

. The proposed method is considered to be simple but uses a correction factor which is untested. Thus it must be seen as a "first approximation". It is hoped that in use the method will become refined and validated. The basic framework of the method can remain but its accuracy can be improved.

. Calculate the useful reduction in air conditioning energy and the useful reduction in emissions of CO_2 and CFCs directly.

. Avoids the necessity of calculating the building energy consumption as a whole. This would normally need the aid of simulation methods which are not available in most architectural firms in developing countries.

. Can easily include the economic dimension.

. Several worksheets have been produced to assist this calculation method.

The calculation of reductions in air conditioning energy consumption, money and the atmospheric pollutants emissions of CO_2 and CFCs as related to changes in U-values, shading and night ventilation is proposed as follows:

1. Calculations of cooling load reductions related to the passive cooling measures related to:

A. Changes of insulation values (U-values) and shading of the building fabric

1. Reduction in external solar gain (walls and roof) S_e

2. Reduction in internal solar gain (windows) S_i

3. Reduction in conductive gains (walls, roof, and windows) C

B. Change in night ventilation rate N

2. The useful total reductions:

The useful reductions (ΔW) = ($\Delta S_e + \Delta S_i + \Delta C$) x f_1 + ΔN x f_2 ....(7.1)

Where f_1 and f_2 are correction factors (discussed in detail in 7.2.6)

Δ denotes "change in"

3. Air conditioning energy reduction (E_{ac}) = (ΔW) / COP

Where COP is the cooling plant efficiency

7.2.2 Changes in the insulation values and shading as related to walls and roof and the reduction of External gains (S_e)

7.2.2.1 The general equation

The calculation of the solar gains through walls and roof depends on the concept of the Solar Heat Gain Factor. The procedure is simply to sum the solar heat gain from the monthly totals falling on each vertical and horizontal plains as follows:

Total useful reduction in external heat gain (S_e) =

[(monthly total rad N vert) x (area of the N wall) x (change in SHF) +
(monthly total rad S vert) x (area of the S wall) x (change in SHF) +
(monthly total rad E vert) x (area of the E wall) x (change in SHF) +
(monthly total rad W vert) x (area of the W wall) x (change in SHF) +
(monthly total rad horizontal) x (area of the roof) x (change in SHF)]
x (correction factor f_1)

7.2.2.2 Monthly direct and diffuse radiation for Jeddah

A. The solar spectrum

The sun radiates a broad spectrum of electromagnetic radiation ranging from far infra-red in the long wave region to ultra-violet in the short wave region. It was estimated that the radiation intensity which falls on to the surface of the atmosphere is about 1.4 kw/m^2. Before reaching the ground a proportion of this energy is absorbed by the atmosphere. The proportion varies depending on the atmospheric conditions but is found to be around 45%, i.e. 800 W/m^2 (the normal intensity of sun's rays at ground level).

Substantial amounts of the radiation is filtered out by the atmosphere in the ultra-violet region. UV is harmful to human skin and all life forms. At high altitudes the sun's rays are significantly richer in UV, therefore, special precaution are needed for those people who live in these regions.

The solar radiation intensity reduction through the atmosphere is induced by two physical processes, absorption and scattering (figure 7.1). The huge reduction of the UV intensity is due to absorption process by ozone molecules which occur in the ionosphere. This causes substantial heating and some of the long wave radiation that is received from the sky comes from this layer.

Absorption of long wave radiation, infra-red, in the lower layer of the atmosphere occurs due to water vapour. This causes convection currents, which together with the absorption of solar radiation at ground level, are shaping the global weather patterns across the world's surface[1].

B. Direct and diffuse solar radiation

The visible light (middle wavelengths) in the lower layers are scattered. Under clear sky conditions the scattering objects are the molecules of oxygen, nitrogen, and water vapour in the air. These are very small and scatter in the short wavelengths. This

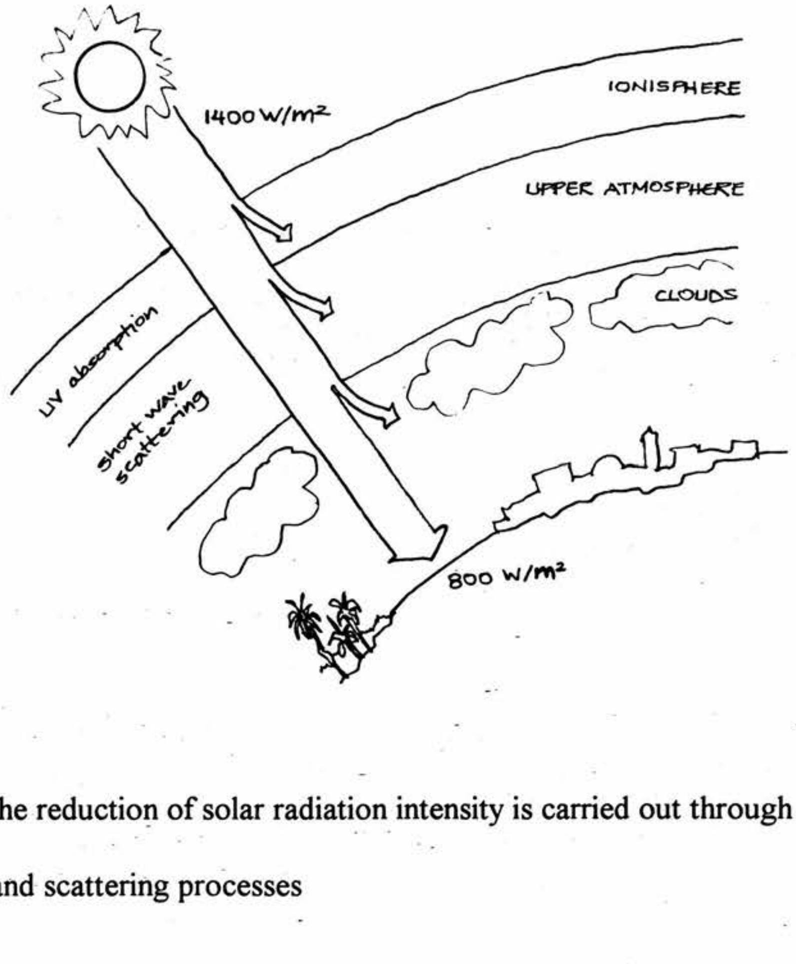


Figure 7.1 The reduction of solar radiation intensity is carried out through absorption and scattering processes

scatter radiation can be seen when looking at the sky and because it is principally the short wave radiation, it looks blue. This radiation is called diffuse as distinct from the radiation direct from the sun which is called direct.

With the existence of large condensed water droplets in the air, i.e. clouds, or large dust particles, then under this condition all visible wavelengths are scattered and the sky looks white. Substantial amounts of light is scattered and usually the sun is completely obscured. In these conditions all radiation is diffuse.

Therefore, the greatest intensity of solar radiation falls on the ground or buildings takes place often when there is a combination of clear sky and white clouds. In this case the building receives the full direct intensity from the sun plus the reflected component from the clouds.

The ground also reflects radiation and therefore adding a further component of radiation to the buildings. The ground-reflected component can be as great as the diffuse component from the sky when its surfaces are light in colour. It is of particularly concern in tropical buildings due to the fact that it causes both glare and thermal gain problems[2].

C. Methods to calculate monthly solar radiation intensities for a site

There are three methods for the prediction of solar radiation in areas with particular microclimate. These are:

a. Extrapolation of available existing data to another site by the use of correlation equations:

. There is a possibility of extrapolating to the site investigated the meteorological data available at other sites by applying empirical regression models.

. Consideration has to be taken to (i) duration of sunshine, (ii) wind direction, and (iii) atmospheric and ground turbidity[3].

b. Computer model for general application: The computer programme is able to estimate the global solar irradiation and its components on any oriented and inclined surface and can be adapted to any physical microclimate conditions of the environment prevailing in a given site. This computer programme called HELIOS developed by Professor Lalas and his group[4]. The programme is based on the method adopted by the European Commission and described by Professor John Page[5] for the production of the European Solar Radiation Atlas.

c. Simplified pocket calculator method: A very simple pocket calculation method for the prediction of monthly means of daily sums of irradiation on a horizontal surface. The method is based partly on the algorithms allowing to characterise the environmental parameters influencing locally the solar radiation and partly on the data published in the CEC Solar Radiation Atlas[6].

The first method will be adopted to predict the solar radiation data for the city of Jeddah. The reasons for this selection are (i) the fact that the other methods require entry data on many parameters prevailing in the site that are not available, (ii) the availability of the statistical package MINITAB to develop the regression models needed and (iii) available solar radiation data for the two cities of Bridgetown and Kingston.

D. Monthly direct and diffuse radiation for Jeddah

Monthly direct and diffuse radiation on eight vertical and horizontal surfaces for Jeddah have been predicted through regression analysis (Table 7.4) of the available data for the two cities of Bridgetown, Barbados (Table 7.2) and Kingston, Jamaica (Table 7.3) prepared by D. Hoch[7] using the Professor Page's method[8]. The general characteristics of these three cities are listed in Table 7.5.

7.2.2.3 Insulation values and the concept of Solar Heat Gain Factor (SHF)

A. Solar heat gain definition

The solar heat gain factor will determine the proportion of incident solar radiation which will pass through a building element when the external and internal air temperatures are equal. Koenigsberger et al[9] have defined SHF as the heat flow rate through the construction due to solar radiation expressed as a fraction of the incident solar radiation. If the intensity of incident solar radiation is I (Watts/m^2) and the rate of heat transfer through the construction is q (Watts/m^2) then the solar heat gain factor will be q/I (a dimensionless proportion). The SHF concept is shown in figure 7.2.

Table 7.2 Monthly radiation totals (Kwh/m^2) for Bridgetown, Barbados, Latitude 13° 06' N.

	Vertical										Horizontal	
	South		SE/SW		E/W		NE/NW		North			
	D	DF	D	DF	D	DF	D	DF	D	DF	D	DF
Jan	104	34	85	34	56	34	11	34	0	34	102	52
	104	49	85	49	56	49	11	49	0	49	102	52
	104	65	85	65	56	65	11	65	0	65	102	52
	104	80	85	80	56	80	11	80	0	80	102	52
Feb	65	34	62	34	51	34	16	34	0	34	96	53
	65	49	62	49	51	49	16	49	0	49	96	53
	65	64	62	64	51	64	16	64	0	64	96	53
	65	79	62	79	51	79	16	79	0	79	96	53
Mar	35	41	51	41	61	41	26	41	0	41	118	63
	35	59	51	59	61	59	26	59	0	59	118	63
	35	77	51	77	61	77	26	77	0	77	118	63
	35	95	51	95	61	95	26	95	0	95	118	63
Apr	0	42	24	42	52	42	30	42	1	42	104	67
	0	59	24	59	52	59	30	59	1	59	104	67
	0	76	24	76	52	76	30	76	1	76	104	67
	0	93	24	93	52	93	30	93	1	93	104	67
May	0	43	9	43	55	43	38	43	41	43	114	68
	0	61	9	61	55	61	38	61	41	61	114	68
	0	80	9	80	55	80	38	80	41	80	114	68
	0	98	9	98	55	98	38	98	41	98	114	68
Jun	0	42	1	42	48	42	36	42	50	42	101	67
	0	59	1	59	48	59	36	59	50	59	101	67
	0	76	1	76	48	76	36	76	50	76	101	67
	0	92	1	92	48	92	36	92	50	92	101	67
Jul	0	43	4	43	52	43	38	43	48	43	109	68
	0	61	4	61	52	61	38	61	48	61	109	68
	0	78	4	78	52	78	38	78	48	78	109	68
	0	96	4	96	52	96	38	96	48	96	109	68
Aug	0	43	16	43	48	43	30	43	20	43	98	70
	0	60	16	60	48	60	30	60	20	60	98	70
	0	77	16	77	48	77	30	77	20	77	98	70
	0	94	16	94	48	94	30	94	20	94	98	70
Sep	14	41	34	41	50	41	24	41	0	41	98	65
	14	57	34	57	50	57	24	57	0	57	98	65
	14	73	34	73	50	73	24	73	0	73	98	65
	14	90	34	90	50	90	24	90	0	90	98	65
Oct	47	39	49	39	45	39	16	39	0	39	86	64
	47	54	49	54	45	54	16	54	0	54	86	64
	47	69	49	69	45	69	16	69	0	69	86	64
	47	84	49	84	45	84	16	84	0	84	86	64
Nov	75	35	64	35	45	35	10	35	0	35	81	56
	75	48	64	48	45	48	10	48	0	48	81	56
	75	62	64	62	45	62	10	62	0	62	81	56
	75	76	64	76	45	76	10	76	0	76	81	56
Dec	88	34	71	34	45	34	9	34	0	34	82	55
	88	48	71	48	45	48	9	48	0	48	82	55
	88	62	71	62	45	62	9	62	0	62	82	55
	88	75	71	75	45	75	9	75	0	75	82	55

D = Direct , Df = Diffused
Prepared by: D. Hoch
Source : Baker N. (1987), Passive and Low Energy Building Design for Tropical Island Climates, Commonwealth Secretariat Publications; London, p. 136. and 137

Table 7.3 Monthly radiation totals (Kwh/m^2) for Kingston, Jamaica, Latitude 17° 58' N.

	Vertical										Horizontal	
	South		SE/SW		E/W		NE/NW		North			
	D	DF	D	DF	D	DF	D	DF	D	DF	D	DF
Jan	91	32	73	32	45	32	8	32	0	32	76	52
	91	45	73	45	45	45	8	45	0	45	76	52
	91	58	73	58	45	58	8	58	0	58	76	52
	91	71	73	71	45	71	8	71	0	71	76	52
Feb	62	33	56	33	43	33	12	33	0	33	77	53
	62	46	56	46	43	46	12	46	0	46	77	53
	62	59	56	59	43	59	12	59	0	59	77	53
	62	72	56	72	43	72	12	72	0	72	77	53
Mar	32	41	40	41	42	41	18	41	0	41	80	67
	32	56	40	56	42	56	18	56	0	56	80	67
	32	70	40	70	42	70	18	70	0	70	80	67
	32	85	40	85	42	85	18	85	0	85	80	67
Apr	1	42	25	42	44	42	24	42	1	42	87	69
	1	58	25	58	44	58	24	58	1	58	87	69
	1	74	25	74	44	74	24	74	1	74	87	69
	1	89	25	89	44	89	24	89	1	89	87	69
May	0	44	9	44	34	44	23	44	20	44	70	74
	0	59	9	59	34	59	23	59	20	59	70	74
	0	73	9	73	34	73	23	73	20	73	70	74
	0	88	9	88	34	88	23	88	20	88	70	74
Jun	0	44	5	44	38	44	28	44	32	44	79	72
	0	59	5	59	38	59	28	59	32	59	79	72
	0	74	5	74	38	74	28	74	32	74	79	72
	0	89	5	89	38	89	28	89	32	89	79	72
Jul	0	45	9	45	46	45	33	45	34	45	95	73
	0	62	9	62	46	62	33	62	34	62	95	73
	0	78	9	78	46	78	33	78	34	78	95	73
	0	95	9	95	46	95	33	95	34	95	95	73
Aug	0	44	15	44	35	44	22	44	1	44	71	73
	0	58	15	58	35	58	22	58	1	58	71	73
	0	72	15	72	35	72	22	72	1	72	71	73
	0	87	15	87	35	87	22	87	1	87	71	73
Sep	16	40	29	40	36	40	17	40	0	40	70	67
	16	54	29	54	36	54	17	54	0	54	70	67
	16	68	29	68	36	68	17	68	0	68	70	67
	16	81	29	81	36	81	17	81	0	81	70	67
Oct	41	37	40	37	34	37	11	37	0	37	63	62
	41	50	40	50	34	50	11	50	0	50	63	62
	41	62	40	62	34	62	11	62	0	62	63	62
	41	75	40	75	34	75	11	75	0	75	63	62
Nov	67	32	55	32	36	32	8	32	0	32	62	53
	67	44	55	44	36	44	8	44	0	44	62	53
	67	55	55	55	36	55	8	55	0	55	62	53
	67	67	55	67	36	67	8	67	0	67	62	53
Dec	63	31	50	31	30	31	5	31	0	31	51	52
	63	42	50	42	30	42	5	42	0	42	51	52
	63	52	50	52	30	52	5	52	0	52	51	52
	63	62	50	62	30	62	5	62	0	62	51	52

Prepared by: D. Hoch
Source : Baker N. (1987), Passive and Low Energy Building Design for Tropical Island Climates, Commonwealth Secretariat Publications; London, p. 137.

Table 7.4 Predicted monthly radiation totals (Kwh/m^2) for Jeddah, Saudi Arabia, Latitude 21° 29' N.

	Vertical										Horizontal	
	South		SE/SW		E/W		NE/NW		North			
	D	DF	D	DF	D	DF	D	DF	D	DF	D	DF
Jan	78	30	60	30	32	30	4	30	0	30	44	49
	78	42	60	42	32	42	4	42	0	42	44	49
	78	54	60	54	32	54	4	54	0	54	44	49
	78	66	60	66	32	66	4	66	0	66	44	49
Feb	53	31	47	31	30	31	7	31	0	31	46	50
	53	43	47	43	30	43	7	43	0	43	46	50
	53	55	47	55	30	55	7	55	0	55	46	50
	53	67	47	67	30	67	7	67	0	67	46	50
Mar	28	38	34	38	30	38	12	38	0	38	50	70
	28	52	34	52	30	52	12	52	0	52	50	70
	28	65	34	65	30	65	12	65	0	65	50	70
	28	79	34	79	30	79	12	79	0	79	50	70
Apr	1.5	39	22	39	32	39	17	39	1	39	60	73
	1.5	54	22	54	32	54	17	54	1	54	60	73
	1.5	69	22	69	32	69	17	69	1	69	60	73
	1.5	83	22	83	32	83	17	83	1	83	60	73
May	0	41	10	41	22	41	17	41	12	41	36	80
	0	55	10	55	22	55	17	55	12	55	36	80
	0	68	10	68	22	68	17	68	12	68	36	80
	0	82	10	82	22	82	17	82	12	82	36	80
Jun	0	41	7	41	26	41	21	41	20	41	49	77
	0	55	7	55	26	55	21	55	20	55	49	77
	0	69	7	69	26	69	21	69	20	69	49	77
	0	83	7	83	26	83	21	83	20	83	49	77
Jul	0	42	10	42	34	42	25	42	21	42	72	79
	0	58	10	58	34	58	25	58	21	58	72	79
	0	73	10	73	34	73	25	73	21	73	72	79
	0	88	10	88	34	88	25	88	21	88	72	79
Aug	0	41	15	41	24	41	16	41	1	41	37	79
	0	54	15	54	24	54	16	54	1	54	37	79
	0	67	15	67	24	67	16	67	1	67	37	79
	0	81	15	81	24	81	16	81	1	81	37	79
Sep	14	38	26	38	25	38	12	38	0	38	39	67
	14	50	26	50	25	50	12	50	0	50	39	67
	14	63	26	63	25	63	12	63	0	63	39	67
	14	75	26	75	25	75	12	75	0	75	39	67
Oct	35	35	34	35	22	35	7	35	0	35	26	63
	35	47	34	47	22	47	7	47	0	47	26	63
	35	58	34	58	22	58	7	58	0	58	26	63
	35	70	34	70	22	70	7	70	0	70	26	63
Nov	57	30	46	30	23	30	4	30	0	30	24	50
	57	41	46	41	23	41	4	41	0	41	24	50
	57	51	46	51	23	51	4	51	0	51	24	50
	57	62	46	62	23	62	4	62	0	62	24	50
Dec	54	29	42	29	17	29	2	29	0	29	8	49
	54	39	42	39	17	39	2	39	0	39	8	49
	54	49	42	49	17	49	2	49	0	49	8	49
	54	58	42	58	17	58	2	58	0	58	8	49

Table 7.5 General characteristics of Bridgetown, Kingston and Jeddah.

City	**Bridgetown (Barbados)**	**Kingston (Jamaica)**	**Jeddah (Saudi Arabia)**
Latitude	13° 06' N.	17° 58' N.	21° 29' N.
Altitude	55 m	34 m	6 m
Climate	Hot-humid	Hot-humid	Hot-humid

Source: Pearce, E. and Smith, C. (1984). The World Weather Guide, Hutchinson & Co.; London. pp. 276, 322 a,d 328.

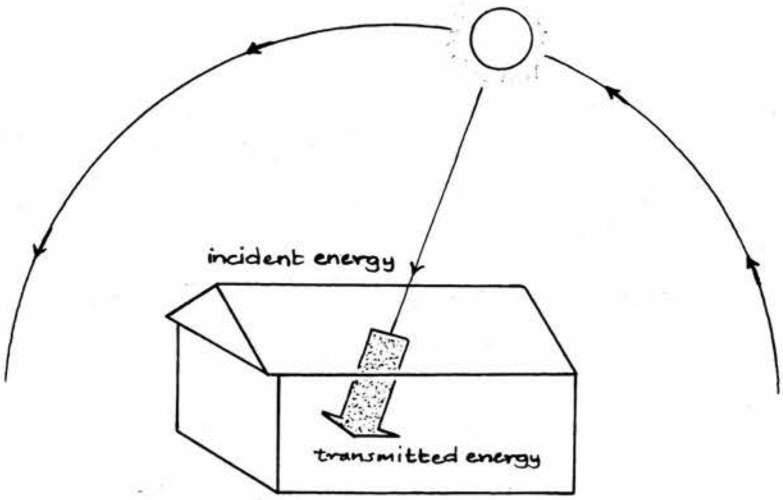


Figure 7.2 The definition of Solar Heat Gain Factor concept

The solar heat gain factor includes the effect of the absorptivity of the surface to radiation. The absorptivity of the surface or the proportion of incident solar radiation absorbed varies with the wavelength of the radiation which in turn relies on the temperature of the surface emitting the radiation. Buildings are subject to radiation from two distinct ranges of wavelengths; (i) the radiation from the sun which is characterised by high temperature, short-wave radiation close to or within the visible portion of the radiation spectrum (ii) the radiation emitted by building surfaces, the ground, etc, and characterised by low temperature long-wave radiation (invisible). The absorptivity of a surface is the same as the emissivity for radiation of the same wavelength. The emissivity is defined as the property of the surface which determines the rate at which radiation is emitted as a proportion of the total radiation which could be emitted at that surface temperature. Normally under a low temperature of between about 0 to 40 °C, building surfaces will emit radiation[10]. A detailed discussion on absorptivity values are in section 7.2.2.3 D.

The formula for the solar heat gain factor is obtained from the concept of the sol-air temperature. The sol-air temperature is the theoretical temperature of the air which results in the same rate of heat transfer through the element, and the same gradient of temperature within the element, as the combined effect of a given intensity of radiation and a given level of air temperature. The formula for sol-air temperature in a simplified form is as follows:

$$t_{sa} = t_0 + \propto Ir_0 - x$$

where; t_{sa} = the sol-air temperature
t_0 = external air temperature

$\propto$ = Absorptivity of the surface to solar radiation
I = incident solar radiation (direct and diffuse)
r_0 = external surface resistance
x = drop in temperature due to radiation emitted from the surface (this factor is sometimes neglected for simplicity).

B. U-values and the SHF calculations for walls and roofs[11]

The heat flow through a roof or wall subject to solar radiation per unit area (neglecting the drop in temperature due to emitted radiation) will therefore be:

$$q = U.dt = U\ (t_{sa} - t_i)$$

$$= U\ (t_0 - \propto.I.r_0 - t_i)$$

If the temperature of the air inside is the same as outside

i.e. $t_0 = t_i$, then:

$$q = U. \propto. I. r_0$$

$$q/I = U. \propto. r_0,$$

Since the solar heat factor is used to find out the maximum proportion of solar radiation which may be transmitted to the interior, the value of r_0 (the external surface resistance) should be selected for hot conditions. The resistance for walls and roofs is 0.05 for normal surfaces, and 0.078 for shiny metallic surfaces. These values consider low air movement and low heat loss to the outside air, resulting in greater surface temperatures and greater heat transfer through the element.

$$q/I = 0.05\ U\ .\ \alpha \text{ (for normal surfaces)}$$

$$= 0.078\ U\ .\ \alpha \text{ (for metallic surfaces)}$$

and can be expressed in percentages as follows;

$$q/I\ \% = 0.05\ U \cdot \alpha\ \% \quad \text{(for normal surfaces)}$$

$$= 0.078\ U \cdot \alpha\ \% \quad \text{(for metallic surfaces)}$$

The formula indicates that the amount of heat passing through the roof or wall, when solar radiation falls on the external surface, depending on (i) the absorptivity of the surface and (ii) the U value. The calculations of U-value and the absorptivity will be further discussed in the following sections.

C. U-values

1. Calculation of U-value

The value of the thermal transmittance can be calculated, from the thermal resistance of the component of the materials, and can be measured practically by subjecting heat to the element and measuring the surface and air to air temperature difference across the element. The calculated values of the thermal transmittance were compared with measured values at the British Research Station (BRS), Wall and Roof Laboratories, and it has been found that the measured values are about 12% higher than those calculated[12]. Accordingly, measured U-values are not accepted as a standard value due to the fact that the conditions of the tests may not agree with the conditions assumed for the calculation. There are many references such as the CIBSE Guide, ASHRAE Handbook of Fundamentals and Building Research Establishment (BRE) Digest no. 108, and many other published papers which give conductivity and U-values for a range of typical building materials and elements which can be used for further assistance during the calculation procedures.

2. Thermal Resistance (R)

The thermal resistance of a building element or airspace express the capability of that material to resist the flow of the heat. The thermal resistance is calculated as follows[13]:

$$\textbf{Thermal resistance (R)} = \frac{\text{the thickness of the element}}{\text{material conductivity } (\lambda)}$$

or **Thermal resistance (R)** = material's resistancy (r) x its thickness

Where r = the reciprocal of the material's conductivity (λ)

3. Thermal resistance of airspace

The transfer of heat between surfaces separated by an airspace occurs by radiation, convection and conduction. The airspace in modern buildings is often used to insulate and protect the internal environment from the effect of the external environment by increasing the envelope layers and reducing the heat flows through it. The resistance of sealed airspace is defined as the reciprocal of the quantity of heat transferred in the steady state in unit time between unit area of the boundary surfaces when their temperatures vary by one degree[14]. Tables 7.6 and 7.7 show the thermal conductance and resistance of some air cavities. The thermal resistance of air space depends on four factors:

1. The emissivity factor (E) of the surfaces enclosing the airspace.

2. The thickness of the airspace cavity.

Table 7.6 Conductance of unventilated cavities

Cavity	Conductance (Wm^{-2} $°C^{-1}$) Unfaced	Faced on one side with bright Aluminium foil
Vertical		
5 mm wide	10.0	5.0
10 mm wide	7.0	3.5
20 mm wide	5.8	2.9
25 mm wide	5.6	2.8
50 mm wide	5.5	2.7
100 mm wide	5.5	2.7
Horizontal		
Unfaced 20 mm wide		
Heat flow up	6.5	
Heat flow down	5.3	
Unfaced 100 mm wide		
Heat flow up	6.1	
Heat flow down	5.3	

Source: Harkness, E. and Mehta, M. (1978), Solar Radiation Control in Building, Applied Science Publishers LTD; London, p. 99.

Table 7.7 Standard thermal resistance of unventilated air-spaces

Type or thickness	Surface emissivity	Thermal resistance (m^2 K W^{-1}) Heat flow horizontal or upwards	Thermal resistance (m^2 K W^{-1}) heat flow downwards
5 mm	High	0.11	0.11
	Low	0.18	0.18
20 mm or more	High	0.18	0.21
	Low	0.35	1.06
High-emissivity planes and corrugated sheets in contact		0.09	0.11
Low-emissivity multiple foil insulation with air-space on one side		0.62	1.76

Source: Buildings, Climate and Energy, p. 275

3. The amount of ventilation of the airspace cavity.

4. The direction of the heat flow.

The surface emissivity has a direct effect on the airspace resistance where the use of different materials can increase or decrease the airspace resistance. For instance, air spaces lined with low emissivity material such as aluminium foil have a much higher resistance because the radiation is largely prevented from occurring. The thickness of the airspace in the cavity influences the quality of the airspace resistance- the greater the thickness the greater the thermal resistance, until it reaches a virtually constant resistance. IHVE Guide (1970) reported that a vertical airspace of about 20 mm thick provide an optimum resistance. The airspace ventilation also provides an additional heat flow path, which decreases the effectiveness of the airspace resistance. Furthermore, the horizontal airspace presents a higher resistance to downward than to upward heat flow because of the creation of convection currents due to the temperature difference across the space. However, the thermal resistance of the airspace is high due to its low thermal conductivity, but it is still less than that of many insulating materials. This is perhaps because a large amount of heat is transferred by radiation across the airspace, the reminder being by convection[15]. The transfer of heat by both radiation and convection can be calculated by the following formulas:

1. Heat transfer by radiation

$$H_r = F_e\ A\,(T_1^{\,4} - T_2^{\,4})$$

and when T_1 comes close to T_2 the formula becomes

$$H_r = F_e\ A\,(T_1 - T_2)$$

where, h_r is the radiation heat transfer

T_1 and T_2 is the absolute temperature of surfaces = Stefan-Boltzman constant

F_e is the emissivity of the surface

A is the area of the surface

2. Heat transfer by convection

$H_c = h_c\ (\phi_1 - \phi_2)$

where, H_c is the convection heat transfer

h_c is the convection coefficient

ϕ_1 and ϕ_2 the temperature of the inner leaf and outer leaf

However, airspace resistance is the reciprocal of the heat transferred by radiation and convection.

$R_c = \wedge \phi\ (H_r + H_c)$

where; Rc is the resistance of the airspace

$\wedge \phi$ is the mean temperature difference in Fahrenheit

H_r and H_c heat transferred by radiation and convection

D. Absorptivity values

The external surfaces of a building envelope usually consist of different materials, each of which behaves differently according to its individual properties. The external surface of a material has three properties determining behaviour with respect to radiant heat exchange. These properties are absorptivity, reflectivity, and emissivity. The absorptivity is the ratio of the amount of solar radiation absorbed by a surface to that which falls on it. The reflectivity is the ratio of the amount of solar radiation reflected by a surface to that which falls on it. The emissivity is the ratio of the thermal radiation from unit area of a surface to the radiation from unit area of a perfect black surface[16].

Most surfaces absorb part of the incident radiation and reflect the remaining part. However, in some surfaces, the falling radiation on an opaque surface is totally absorbed, which is the case with a perfect black surface, or it is totally reflected, as is the case with a perfect white surface. In every case, the sum of the absoptivity which is denoted by (a) the reflectivity, denoted by (r), should be equal to one.

Hence $r = 1 - a$

The emissivity of a surface is its relative ability to emit radiant energy. The emissivity (E) and absoptivity (a), are sometimes numerically equal for any specific wavelength, but they may differ for different wavelengths. All surfaces emit radiation and the intensity of that radiation depends on their surface temperature.

$E = a = 1 - r$

The absorption or reflection of heat is very much affected by the colour of the building surfaces, so that the use of light colours is effective in reducing the heat gain in the building. Even though the colour of a surface gives good indication of its absorptivity for solar radiation, it does not indicate the behaviour of a surface with respect to long wave radiation. Black and white surfaces have a different absorptivity for solar radiation, (where the black surface absorbs more heat than the white surface during their exposure to the sun), but they have similar emissivity for long wave radiation. Cooling by exposure to the night is therefore similar for both black and white surfaces. Considering the different surface characteristics of opaque materials, it is important to use a light colour material for the exterior surfaces of buildings in hot arid region. Tables (7.8, 7.9 and 7.10) give typical values for absorptivity for some building elements and surfaces.

E. Chart for SHF calculation

Evans[17] has proposed a chart for calculating the SHF of a wall or roof construction and produce various values of SHF for typical constructions (table 7.11). The chart is shown in figure (7.3) and can be filled in as follows:

1. Identify the building element at the top of the chart.
2. Define the layers of construction and their thickness in meters
3. Obtain the resistivity of materials "r" (from tables) and record them in row .
4. Find the resistance of each layer by multiplying "r" and the layer's thickness.
5. Find the total resistance by adding all the resistance.
6. Calculate the U value (1/R) from the total resistance of the construction and plot it in the corresponding box.
7. Find the absorptivity of the external surface to solar radiation (tables 7.8, 7.9, and 7.10).

Table 7.8 Typical admittance values for walls, floors and ceilings

Element construction	Admittance (W/m^2 deg C)
WALLS:	
Lightweight or hollow block, more than 75mm thick	3.0
Hollow concrete or perforated clay block, more than 75mm thick	4.0
Brick, more than 75mm thick	5.0
Concrete, more than 75mm thick	6.0
Two fibre board sheets 0.013m thick with air space between them	2.0
Partitions of material over 1100 kg/m^3 with a lining of resistance 0.18 m^2 deg C/W	3.0
FLOORS:	
Dense concrete	6.0
Concrete covered with carpet, wood block or cork tile	3.0
Suspended timber floor	2.0
Suspended timber floor covered with carpet	1.5
CEILINGS:	
Plastered concrete	6.0
Plasterboard, cavity and dense slab	3.0
Lath and plaster or plasterboard ceiling with roof cavity and pitched roof	2.0

Source: M. Evans, Housing, Climate and Comfort, p. 161.

Table 7.9 Absorptivity, reflectivity and emissivity of some surfaces

Surface	Absorptivity Solar radiation	Reflectivity Solar radiation
Aluminium	0.20	0.80
Asbestos	0.60	0.40
Brass (polished)	0.30	0.70
Brick	0.60	0.40
Concrete	0.65	0.35
Marble (white)	0.45	0.55
Paint		
Aluminium	0.50	0.50
White	0.30	0.70
Green	0.70	0.30
Black	0.90	0.10

Source: Harkness, E. and Mehta, M. (1978), Solar Radiation Control in Building, Applied Science Publishers LTD; London, p. 98.

Table 7.10 Solar radiation absorption coefficient

Surface	Absorptivity for solar radiation	Surface	Absorptivity for solar radiation
WALLS		**ROOFS**	
White brick tile	0.30	White asbestos cement	0.50
Yellow brick tile	0.39	Cooper sheeting	0.64
White stone	0.40	Uncoloured roofing tile	0.67
Light fletton brick	0.45	Red roofing tile	0.70
Cream brick tile	0.50	Galvanized iron, clean	0.77
Buff brick tile	0.60	Lead sheeting	0.79
Light fawn stock brick	0.64	Cedar shingles	0.80
Dark fletton brick	0.65	Brown roofing tile	0.87
Concrete	0.70	Blue-grey slate	0.87
Red brick tile	0.70	Bituminous felt	0.89
Pebble dash	0.71	Galvanized iron, dirty	0.89
Red sand-lime brick	0.72	Grey slate	0.90
Rough cast	0.75	Black roofing tile	0.92
White sand stone	0.76	Asphalt waterproofing course	0.95
Stone rubble	0.80		
Blue brick tile	0.88		
PAINTS		**SURROUNDINGS**	
Whitewash	0.21	Sea or lake water	0.29
Bright aluminium	0.30	Snow	0.30
Glossy white	0.30	Concrete	0.70
Flat white	0.35	Silver sand	0.70
Gilt	0.40	Grass	0.80
Yellow	0.58	Sand, grey	0.82
Bronze	0.50	Rock	0.84
Silver-grey	0.53	Hardwoods in leaf	0.85
Dark aluminium	0.63	Moorland	0.86
Bright red	0.65	Earth and ploughed fields 0.92	
Brown	0.70	Black soil, pine, spurce forest	0.99
Slate	0.71		
Light green	0.73	**MISCELLANEOUS**	
Medium red	0.74		
Medium green	0.85	White leaves or grass	0.20
Dark green	0.95	Aluminium foil	0.39
Blue	0.97	Light-coloured leaves	0.55
Black	0.97	Yellow leaves	0.58

Source: Groundwater, I. (1957). Solar Radiation in Air Conditioning, Richard Clay and Company LTD; Suffolk, pp.38 & 39.

Table 7.11 SHF for typical construction by Evans.

Construction	U value	SHF	Admittance
	U	q/I	
	$W/m^2\,°C$	%	$W/m^2\,°C$
ROOFS			
1 Aluminium sheet (new)	8.7	10.2	na
2 Galvanized iron sheet (new)	8.5	20.0	na
3 As 2, but rusty	8.5	34.0	na
4 Aluminium sheet, roof cavity, asbestos cement sheet ceiling	1.9	4.4	2
5 As 4 with 50 mm fibre glass cavity	1.3	3.0	2
6 Rusty galvanised iron sheet, cavity and thin sheet ceiling	1.9	6.7	2
7 As 6 with 50 mm fibre glass	1.3	5.2	2
8 150 mm concrete slab	3.3	9.1	6
9 As 8 with 50 mm wood wool slab	1.13	3.1	3
10 As 9 with external insulation	1.13	3.1	6
11 As 8 with external & internal insulation	0.75	2.1	3
12 As 8 but whitewashed externally	3.3	4.1	6
13 As 9 but whitewashed externally	1.13	1.4	3
14 As 10 but whitewashed externally	1.13	1.4	6
15 As 11 but whitewashed externally	0.75	0.9	3
16 300 mm concrete slab	2.46	6.7	6
WALLS			
17 250 mm hollow concrete blocks rendered both sides	1.7	4.7	4
18 As 17 with whitewash externally	1.7	2.1	4
19 Window with single glazing	4.0	85	na
20 Open window	na	100	na
21 230 mm brick wall	2.7	9.5	5
22 As 21 with whitewash externally	2.7	3.4	5
23 280 mm brick wall with 50 mm cavity	1.7	6	5
24 As 23 with whitewash externally	1.7	2.1	5
25 Corrugated asbestos cement sheet	8.0	16	na
26 As 25 with 50 mm wood wool slab and cavity between slab sheet	1.2	2.4	2

Source: M. Evans, Housing, Climate and Comfort, p. 84

Solar heat gain factor calculation						
Wall or roof copo-nents		1	2	3	4	5
Width						
Conductivity						
T. resistant						
U value						
Absorptivity value						
SHF	0.05					
	0.078					

Figure 7.3 Chart for SHF calculation

8. Calculate the solar heat gain factor using the appropriate formula:

$q/I\% = 5.U.a$ (for normal surfaces)

$q/I\% = 7.8.U.a$ (for metallic surfaces)

7.2.2.4 Shading and the concept of SHF

In calculating the reduction due to shading of wall or roof over a period of time, only under perfect shading is all radiation intercepted. This is due to two reasons:

1. The shading device such as adjacent building, tree, overhang, etc, may not provide shading to all of the wall in all the time.
2. Solar energy will always fall on to the surface through the diffuse sky and the reflected solar radiation from the ground.

The geometry of the shading device determines the relative amounts of unshaded diffuse radiation.

The calculation of shading factor that could be used to multiply the monthly radiation total falling on to a surface when evaluating the actual total after shading, require an hour-by-hour calculation of shadow geometry, and hourly values of direct, diffuse, and reflected radiation. This is beyond the scope of a manual method. Thus the proposed approach relies upon some simplifying assumptions and estimations as follows:

1. Roofs and walls are either "distant shaded" where the surface continue to receive

substantial amounts of diffuse radiation, or "close shaded", where direct and almost all diffuse radiation is intercepted.

2. In the calculation of the diffuse monthly total presented in the tables, the ground reflectance is taken into account.
3. Intermediate shading systems, i.e. between "close" and "distance" may be regarded to shade part of the diffuse total and be judged by estimation.
4. Shading of a surface for part of the day is accounted for by estimating the fraction of the surface shaded from direct sun, when the sun azimuth is normal to the wall azimuth. This is called the Average Shading Coefficient (ASC).
5. As far as distance shading is concerned, the ASC is applied only to the direct monthly solar total.

The change in SHF can be due to the increase of shading or to the change of walls, roof's transmittance U-values and absorption values. In the first case the original SHF is multiplied by a shading factor.

7.2.2.5 SHF for proposed modified walls and roofs

The solar heat gain factors of existing walls and roofs as well as the proposed modified walls and roofs due to changes in U-values have been calculated and presented in table 7.12, 7.13.

Table 7.12 Description of the various building and insulation materials proposed for existing walls and the corresponding thermal conductivity, resistance, transmittance and SHF.

Wall	Materials	Thickness (M)	Conductivity (W/M K)	Resistance (M^2 K/W)	U - value (W/M^2 K)	SHF (%)
	Marble tiles	0.02	2.00	0.01	1.770	3.98
	Sand cement mortar	0.05	0.530	0.094		
	Hollow concrete block	0.22	0.510	0.431		
	Inside mortar plaster	0.02	0.663	0.030		
	Total R = 0.565 M^2 K/W U value = 1/R = 1.770 W/M^2 K SHF = 1.77x 0.45x 0.05 = 0.03982					
0	Marble tiles	0.02	2.00	0.01	0.926	2.00
	Sand cement mortar	0.05	0.530	0.094		
	Hollow concrete block	0.22	0.510	0.431		
	Inside mortar plaster	0.02	0.663	0.030		
	Sand cement mortar	0.01	0.663	0.015		
	Calcium silicate brick	0.20	0.400	0.500		
	Total R = 1.080 M^2 K/W U value = 0.926 W/M^2 K					
1	Marble tiles	0.02	2.00	0.01	0.541	1.21
	Sand cement mortar	0.05	0.530	0.094		
	Hollow concrete block	0.22	0.510	0.431		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.025	0.032	0.781		
	Calcium silicate brick	0.20	0.400	0.500		
	Total R = 1.846 M^2 K/W U value = 0.541 W/M^2 K					
2	Marble tiles	0.02	2.00	0.01	0.380	0.85
	Sand cement mortar	0.05	0.530	0.094		
	Hollow concrete block	0.22	0.510	0.431		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.05	0.032	1.562		
	Calcium silicate brick	0.20	0.400	0.500		
	Total R = 2.627 M^2 K/W U value = 0.380 W/M^2 K					
3	Marble tiles	0.02	2.00	0.01	0.293	0.65
	Sand cement mortar	0.05	0.530	0.094		
	Hollow concrete block	0.22	0.510	0.431		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.075	0.032	2.340		
	Calcium silicate brick	0.20	0.400	0.500		
	Total R = 3.405 M^2 K/W U value = 0.293 W/M^2 K					

Wall	Materials	Thickness (M)	Conductivity (W/M K)	Resistance (M^2 K/W)	U - value (W/M^2 K)	SHF (%)
4	Marble tiles	0.02	2.00	0.01	0.679	1.52
	Sand cement mortar	0.05	0.530	0.094		
	Hollow concrete block	0.22	0.510	0.431		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.025	0.032	0.781		
	Inside plaster board	0.02	0.160	0.125		
		Total R = 1.471 M^2 K/W U value = 0.679 W/M^2 K				
5	Marble tiles	0.02	2.00	0.01	0.444	0.99
	Sand cement mortar	0.05	0.530	0.094		
	Hollow concrete block	0.22	0.510	0.431		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.05	0.032	1.562		
	Inside plaster board	0.02	0.160	0.125		
		Total R = 2.252 M^2 K/W U value = 0.444 W/M^2 K				
6	Marble tiles	0.02	2.00	0.01	0.330	0.70
	Sand cement mortar	0.05	0.530	0.094		
	Hollow concrete block	0.22	0.510	0.431		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.075	0.032	2.340		
	Inside plaster board	0.02	0.160	0.125		
		Total R = 3.03 M^2 K/W U value = 0.330 W/M^2 K				
7	Marble tiles	0.02	2.00	0.01	0.664	1.49
	Sand cement mortar	0.05	0.530	0.094		
	Hollow concrete block	0.22	0.510	0.431		
	Inside mortar plaster	0.02	0.663	0.030		
	Air cavity	0.05	2.345	0.426		
	Calcium silicate brick	0.20	0.400	0.500		
		Total R = 1.506 M^2 K/W U value = 0.664 W/M^2 K				

Table 7.13 Description of the various insulation materials proposed for existing roof and the corresponding thermal conductivity, resistance, transmittance and SHF

Roof	Materials	Thickness (M)	Conductivity (W/M K)	Resistance (M2 K/W)	U - value (W/M2 K)	SHF (%)
	Terrazzo tile	0.02	0.840	0.023	2.832	5.664
	Sand cement mortar	0.02	0.530	0.037		
	Sand	0.05	1.745	0.028		
	Waterproofing membrane	0.01	0.500	0.020		
	Reinforced concrete	0.20	0.930	0.215		
	Inside mortar plaster	0.02	0.663	0.030		
		Total R = 0.353 M2 K/W U value = 2.832 W/M2 K				
0	Terrazzo tile	0.02	0.840	0.023	1.096	2.192
	Sand cement mortar	0.02	0.530	0.037		
	Sand	0.05	1.745	0.028		
	Waterproofing membrane	0.01	0.500	0.020		
	Reinforced concrete	0.20	0.930	0.215		
	Inside mortar plaster	0.02	0.663	0.030		
	Air cavity	0.10	2.302	0.434		
	Plaster board	0.02	0.160	0.125		
		Total R = 0.912 M2 K/W U value = 1.096 W/M2 K				
1	Terrazzo tile	0.02	0.840	0.023	0.892	1.784
	Sand cement mortar	0.02	0.530	0.037		
	Sand	0.05	1.745	0.028		
	Waterproofing membrane	0.01	0.500	0.020		
	Reinforced concrete	0.20	0.930	0.215		
	Inside mortar plaster	0.02	0.663	0.030		
	Air cavity	0.10	2.302	0.434		
	Cork board	0.015	0.045	0.333		
		Total R = 1.12 M2 K/W U value = 0.892 W/M2 K				
2	Terrazzo tile	0.02	0.840	0.023	0.681	1.362
	Sand cement mortar	0.02	0.530	0.037		
	Sand	0.05	1.745	0.028		
	Waterproofing membrane	0.01	0.500	0.020		
	Reinforced concrete	0.20	0.930	0.215		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.025	0.032	0.781		
	Cork board	0.015	0.045	0.333		
		Total R = 1.467 M2 K/W U value = 0.681W/M2 K				

Roof	Materials	Thickness (M)	Conductivity (W/M K)	Resistance (M2 K/W)	U - value (W/M2 K)	SHF (%)
3	Terrazzo tile	0.02	0.840	0.023	0.444	0.888
	Sand cement mortar	0.02	0.530	0.037		
	Sand	0.05	1.745	0.028		
	Waterproofing membrane	0.01	0.500	0.020		
	Reinforced concrete	0.20	0.930	0.215		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.05	0.032	1.562		
	Cork board	0.015	0.045	0.333		
		Total R = 2.248 M2 K/W				
		U value = 0.444 W/M2 K				
4	Terrazzo tile	0.02	0.840	0.023	0.330	0.660
	Sand cement mortar	0.02	0.530	0.037		
	Sand	0.05	1.745	0.028		
	Waterproofing membrane	0.01	0.500	0.020		
	Reinforced concrete	0.20	0.930	0.215		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.075	0.032	2.343		
	Cork board	0.015	0.045	0.333		
		Total R = 3.029 M2 K/W				
		U value = 0.330 W/M2 K				
5	Terrazzo tile	0.02	0.840	0.023	0.794	1.588
	Sand cement mortar	0.02	0.530	0.037		
	Sand	0.05	1.745	0.028		
	Waterproofing membrane	0.01	0.500	0.020		
	Reinforced concrete	0.20	0.930	0.215		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.025	0.032	0.781		
	Plaster board	0.02	0.160	0.125		
		Total R = 1.259 M2 K/W				
		U value = 0.794 W/M2 K				
6	Terrazzo tile	0.02	0.840	0.023	0.490	0.980
	Sand cement mortar	0.02	0.530	0.037		
	Sand	0.05	1.745	0.028		
	Waterproofing membrane	0.01	0.500	0.020		
	Reinforced concrete	0.20	0.930	0.215		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.05	0.032	1.562		
	Plaster board	0.02	0.160	0.125		
		Total R = 2.040 M2 K/W				
		U value = 0.490 W/M2 K				
7	Terrazzo tile	0.02	0.840	0.023	0.354	0.708
	Sand cement mortar	0.02	0.530	0.037		
	Sand	0.05	1.745	0.028		
	Waterproofing membrane	0.01	0.500	0.020		
	Reinforced concrete	0.20	0.930	0.215		
	Inside mortar plaster	0.02	0.663	0.030		
	Extruded polystyrene	0.075	0.032	2.343		
	Plaster board	0.02	0.160	0.125		
		Total R = 2.821 M2 K/W				
		U value = 0.354 W/M2 K				

7.2.3 Changes in insulation values and shading as related to windows and the reduction in internal Solar Gains

7.2.3.1 The general equation

This is similar to the external solar gains except that the area of window involved, and the concept of solar gain factor SG is used. Standard Solar Gain Factors are shown in table 7.14. The procedure is to sum the solar heat gain from monthly totals falling on windows in each surface as follows:

Total useful reduction in internal solar gain (S_i) =

[(monthly total radiation E elevation) x (area of opening E wall) x (change in SG) +
(monthly total radiation S elevation) x (area of opening S wall) x (change in SG) +
(monthly total radiation W elevation) x (area of opening W wall) x (change in SG) +
(monthly total radiation N elevation) x (area of opening N wall) x (change in SG) +
(monthly total radiation Horiz.) x (area of opening Horiz) x (change in SG)]
x (correction factor f_2)

7.2.3.2 Insulation values and the concept of Solar Gain factor (SG)

The Solar Gain Factor is influenced by two important factors of (a) transmittance factor which is a function of the radiation transmission of the glass and (b) shading factor. Table 7.15 gives U-values and absorption data for a range of glasses. This shading factor is a property of the opening design itself, i.e. overhangs, fins, louvers, etc. In addition, the shading factor could include the effect of external obstructions such as other buildings or vegetation. The two factors of SG are independent and may be multiplied together, i.e. any existing SG may be modified by

Table 7.14 Solar gain factors for various types of glazing and shading

Solar gain factors for different types of glazing		**Position of shading and types of sun protection**	
single	Double	Type of sun protection	shading
0.76	0.64	None	None
0.51	0.38	Lightly heat absorbing glass	
0.39	0.25	Densely heat absorbing glass	
0.56	-	Lacquer coated glass, grey	
0.26	0.25	Heat reflecting glass, gold	
0.62	0.56	Dark green open weave plastic blind	Internal
0.46	0.46	White venetian blind	
0.41	0.40	White cotton curtain	
0.30	0.33	Cream holland linen blind	
-	0.28	White venetian blind	Mid-pane
0.22	0.17	Dark green open weave plastic blind	External
0.14	0.11	Canvas roller blind	
0.14	0.11	White louvered sunbreaker, blades at 45°	
0.13	0.10	Dark green miniature louvered blind	

Source: CIBSE Guide

Table 7.15 Transmission, absorption and reflection data for a range of glasses

Glass type	Specification	Solar radiant heat Reflectance	Solar radiant heat absorptance	U-value $Wm^{-2} k^{-1}$
A. 'Insulight' Double Glazing with 'Kappafloat' Inner Pane; Outer Glass as Listed				
Clear flat	4mm	0.19	0.31	1.9
	6mm	0.17	0.37	1.9
Spectrafloat	6mm (Bronze)	0.15	0.53	1.9
Antisun float	6mm (Green)	0.08	0.65	1.9
	6mm (Bronze)	0.08	0.65	1.9
	6mm (Grey)	0.08	0.66	1.9
Reflectafloat	6mm (Silver)	0.31	0.42	1.9
Suncool float	6mm (Silver)	0.32	0.63	1.8
	6mm (Bronze)	0.21	0.75	1.8
	6mm (Blue)	0.22	0.69	1.9
B. 'Insulight' Double Glazing with Clear Flat Inner Pane; Outer Glass as Listed				
Clear flat	4mm	0.12	0.21	2.9
	6mm	0.11	0.28	2.9
Spectrafloat	6mm (Bronze)	0.12	0.46	2.9
Antisun float	6mm (Green)	0.06	0.58	2.9
	6mm (Bronze)	0.06	0.58	2.9
	6mm (Grey)	0.06	0.59	2.9
Reflectafloat	6mm (Silver)	0.29	0.37	2.9
Suncool float	6mm (Silver)	0.32	0.62	2.3
	6mm (Bronze)	0.21	0.74	2.3
	6mm (Blue)	0.21	0.67	2.5

Continue Table 7.15

Glass type	Specifi. cation	Solar radiant heat Reflectance	Solar radiant heat absorptance	U-value $Wm^{-2} k^{-1}$
C. Single Glazing				
Clear float	4mm	0.07	0.11	5.4
	6mm	0.07	0.15	5.4
Spectrafloat	6mm (Bronze)	0.10	0.36	5.4
	6mm (Green)	0.05	0.49	5.4
	6mm (Grey)	0.05	0.51	5.4
Reflectafloat	6 mm (Silver)	0.28	0.29	5.4
Suncool float	6 mm (Silver)	0.32	0.60	4.0
	6 mm (Bronze)	0.21	0.73	4.0
	6 mm (Blue)	0.21	0.64	4.5

Source: Applications Manual, Window Design (CIBSE) multiplying by a Shading Factor.

7.2.3.3 Shading and the concept of Solar Gain (SG)

The range of shading options is wide and so is their effectiveness. For some geometric devices, the shading factor may be affected by sun position and orientation. Therefore, the determination of this factor can only be carried out by evaluation on an hour-by hour basis using sunpath diagrams with radiation and shadow mask overlays.

Table 7.14 gives standard Solar Gain Factors for a limited range of shading options. A much fuller range of shading measures is developed by Olgay (Table 7.16). He revealed them in the form of a Shading Transmission Factor, based upon a single-glazed window. These factors range from 0.1 for a fully shaded window by external dark louvers and 1.0 for an un-shaded (totally exposed) single-glazed window. Olgay's shading factors may be used to multiply the basic un shaded Solar Gain Factor for the appropriate glazing.

7.2.3.4 Solar Gain Factor for the proposed measure

From the discussion above, the solar gain factor of existing windows and the same windows with a complete shading are as follows:

SG for existing windows = 0.76

SG for existing windows with complete shading = 0.14

Table 7.16 Olgay's shading transmission Factors

Shading measure	Shading transmission factor
A. Glazing and Inside measures	
single-glazed window	1.00
inside dark (colour) roller blind half drawn	0.91
inside medium (colour) roller blind half drawn	0.81
inside dark (colour) roller blind fully drawn	0.75
inside dark venetian blind fully drawn	0.75
inside light roller blind half drawn	0.71
6 mm tinted glass	0.66
inside medium venetian blind fully drawn	0.65
inside medium roller blind fully drawn	0.62
lightly colour plastic sheeting + glass	0.60
double glaze - one clear, one lightly tinted	0.60
glazing with inside dark grey draped curtain	0.58
inside white venetian blind fully drawn	0.56
6 mm tinted glass + venetian blind fully drawn	0.53
glazing with inside light grey draped curtain	0.47
reflective metalized plastic film on glass	0.60-0.36
inside reflective aluminium venetian blind	0.45
inside white roller blind fully drawn	0.41
glazing with inside white draped curtain	0.40
heavily reflective metalized film between double glass	0.20
b. Outside measures	
outside light louvered awning 2/3 drawn	0.43
outside dark vertical fixed fins (East or West walls)	0.31
outside canvas awning, dark or medium, fully drawn	0.25
overhang, continuous on South or North walls	0.25
outside white venetian blind fully drawn	0.15
outside white louvered awning fully drawn	0.15
outside automatic moveable dark louvers	0.15-0.10
outside automatic moveable dark fins (East or West walls)	0.15-0.10

Source: Olgay V. Design with Climate, Princeton University Press, 1963

7.2.4 Change in insulation values as related to walls, roof and windows and the reduction of conductive gains

7.2.4.1 The general equation

The conductive gain is due to conduction through roof, walls and glazing. It is likely that much of this conductive gain is related to glazing. However, gains through walls or roof may enter the prayer hall several hours later. All conductive gains will be treated as instantaneous and will be calculated from the difference between the Set Point Temperature T_{set} and the average external air temperature during the occupied period:

Useful reduction in conductive gain Δ C =

(mean ambient temperature during occupancy - T_{set}) x

(change in total conductance ΔUA) x (no. occup. hrs/day) x

(no. occup. days/month)/1000

A change of conductive gain could be brought about by (a) lowering T_{set}, (b) a reduction in hours, and (c) a reduction of U-values.

6.2.4.2 The determination of mean ambient temperature during occupancy

To determine the mean ambient temperature during occupancy, the Temperature Grid and Diurnal Swing Overlay (fig. 7.4 and fig. 7.5) are used as follows:

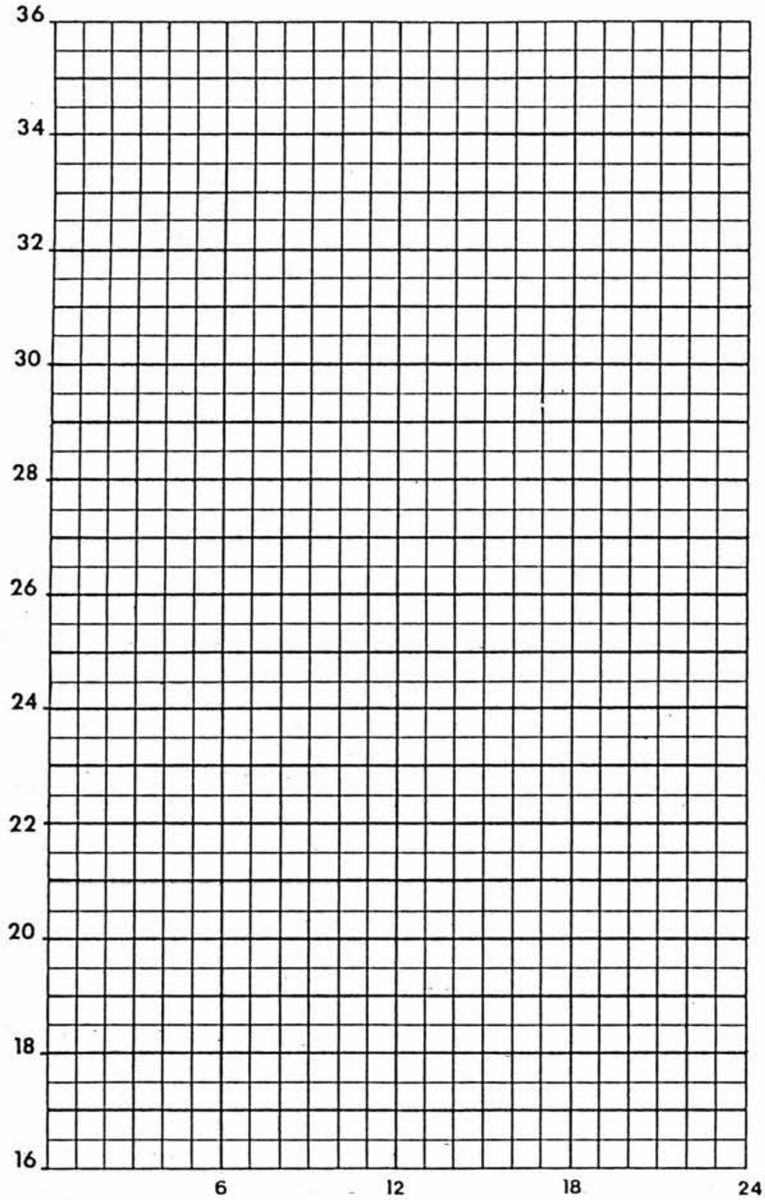


Figure 7.4 PACE temperature grid

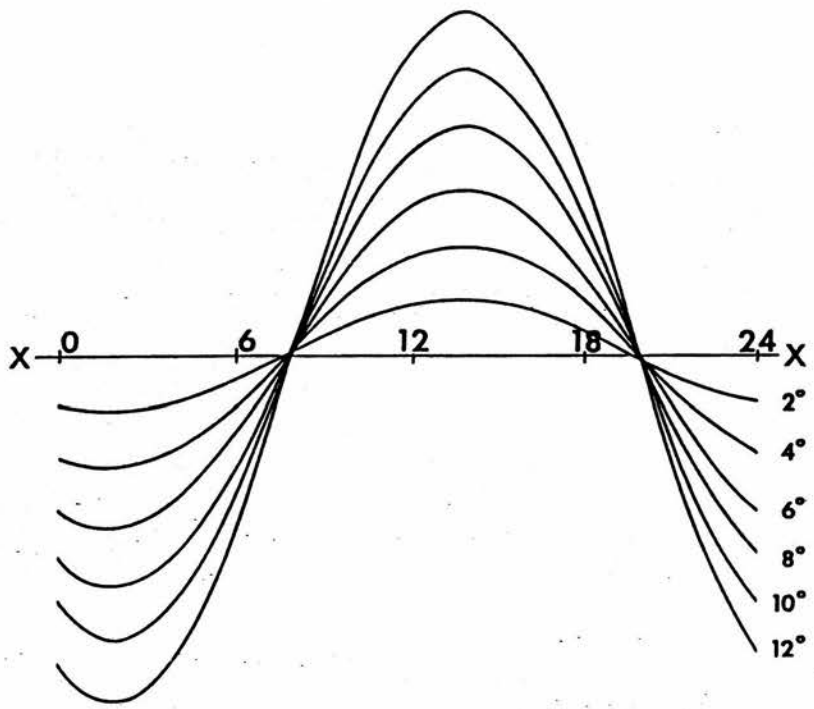


Figure 7.5 PACE diurnal swing overlay

a. By inspecting maximum and minimum temperatures, choose the appropriate diurnal swing curve and trace off on tracing paper. In addition, draw hour axis xx.

b. Locate the traced overlay over the temperature grid and position the xx line on the mean temperature for the month under consideration. The curve now reveals an approximation to the actual hourly temperature.

c. Draw vertical lines on the tracing paper denoting the start and finish of the occupied period.

d. Count the square bounded by the curve, the vertical lines and the xx line, including even those squares cut by the curve. Squares below the xx line count as negative.

e. Each square is calculated as a 0.5 hr °C. The mean temperature during occupancy is calculated as follows:

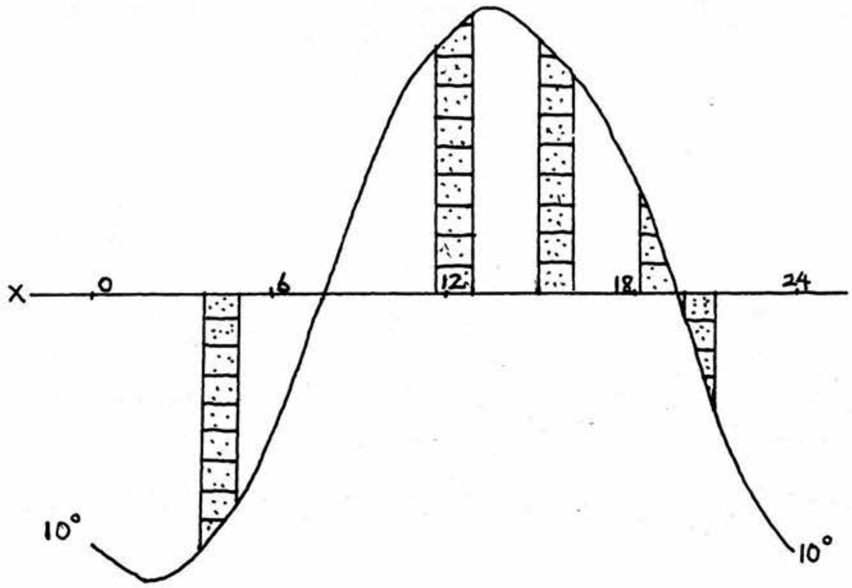
Mean temperature during occupancy = monthly mean temperature + (no. squares) / (2 x occupied hours)

7.2.4.3 The determination of mean ambient temperature during occupancy in Jeddah's mosque

The different mean ambient temperature during occupancy in mosque has been determined by using the method suggested in PACE. The results are shown in Table 7.17. Figure 7.6 reveals an example of calculating the mean temperature during occupancy in the month of February.

Table 7.17 Mean ambient temperature during occupancy in mosque for all months and the calculated degree hours for each month

Months	Mean ambient temp (°C)	mean temp. difference	Occupancy		degree hours per month
			hours/day	days/month	
January	24.48	1.48	5.05	31	233
February	25.31	2.31	5.05	28	328
March	26.40	3.4	5.05	31	533
April	28.67	5.67	5.05	30	860
May	29.95	6.95	5.05	30	1054
June	31.11	8.11	5.05	31	1271
July	31.90	8.90	5.05	31	1394
August	32.20	9.20	5.05	31	1441
September	31.69	8.69	5.05	30	1317
October	30.01	7.01	5.05	31	1098
November	28.76	5.76	5.05	30	874
December	26.37	3.37	5.05	31	529



(20 - 12.33) / 2(5.05) = 0.76
0.76 + 24.55 = 25.31°C
25.31 - 23 = 2.31°C

Figure 7.6 The determination of mean ambient temperature during the occupancy in mosque for the month of February

7.2.5 Change in night ventilation rate and the increase in night ventilation loss

Night ventilation normally takes place when the ambient temperature is below the value of T_{set} (target temperature for air conditioning). In addition, the use of night ventilation occurs outside the occupancy period, therefore some allowance for the ability of the building to carry over the "coolth" into the occupied period next day has been made by using the second correction factor (f_2).

Taking the actual night-time building temperature instead of T_{set} is an alternative approach but this is not known explicitly because the building is free-running after the end of the occupied period. Moreover, the degree to which the building has approached the ambient temperature is a property of the occupancy pattern and the thermal mass.

It is similar to the problem of heating energy calculation using the 'degree day' method. In this method, an implicit mean 24-hour building temperature is calculated for an intermittently heated building by the use of empirical factors considering both issues of occupancy pattern and the thermal mass. These values have been used by Dr. Baker to assist in the derivation of the factor f_2 for the standard occupancy and further manipulated by the author to contain the intermittent occupancy of mosque.

7.2.5.1 The general equation

The useful night ventilation heat loss in Kwh/month is calculated using the following formula:

Useful night ventilation (N) =

$(T_{set} - T_{night}) \times f_2 \times 0.33 \times$ (no. air changes/hr) x (building volume) x (night vent hrs/month)/1000

The Temperature Grid and Overlay is used in determining the T_{set}. This can also be used to indicate the actual duration of useful night ventilation when the ambient temperature drops below T_{set}..

It is not easy to establish the ventilation rate. If night ventilation is carried out by mechanical means, then it will probably be the same as the fresh air intake during the daytime (0.5-1.0 ac/h). Fans normally used to provide recirculation or air movement may be able to be re-directed to increase the night ventilation rate.

A possible solution is to adopt passive night ventilation cooling. This would definitely maximise the use of available wind as the stack-effect ventilation tends to be small since there is small temperature differences. In an air conditioned mosque, passive night ventilation require purpose-provided inlets and outlets. Up to 5 ac/h could be attained if 5% of the wall area on the windward and leeward walls being open. Existing air conditioned mosques possess numerous numbers of windows in their walls scattered in all four sides. In addition, these mosques are built isolated from other buildings and normally within empty plot and therefore ventilation can be easily maintained.

7.2.5.2 The determination of the mean ambient temperature below $T_{set.}$

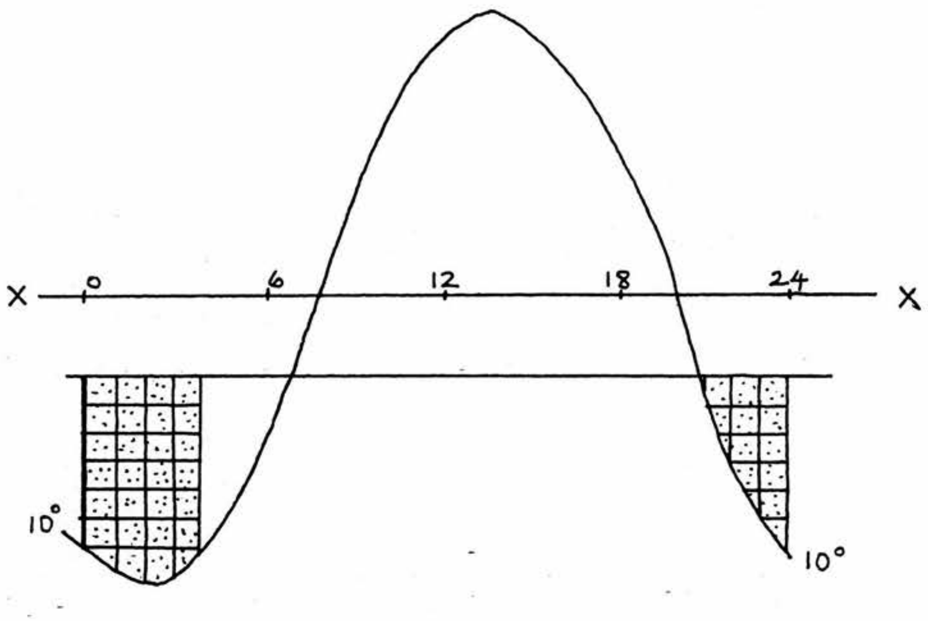
The mean of night temperature below T_{set} has been calculated by using the method suggested above. The results are shown in Table 7.18. An example is shown in Figure 7.7 where the calculation of the mean ambient temperature below T_{set} during the month of February.

7.2.6 Correction factors

The first correction factor applied to solar (external and internal) and conductive gains is connected with the fact that not all of the reduction in this gain will be achieved as a reduction in cooling load. Some of the heat gain will be stored by the building fabrics during the occupied period and then lost during the unoccupied hours - provided the ambient temperature at this time is below that of the building mean temperature. The value of this factor cannot be set without detailed simulation, therefore the values of this factor as developed by Baker[18] (table 7.19) for different occupancy patterns (1 to 4) will be used. Dr Baker has estimated these figures as he modified the concept of the "alternating solar heat gain factors" derived from the Admittance Method[19]. By a closer look on the table none of these figures can be applied in calculating the reduction of cooling load in mosques due to the fact that mosques have different occupancy patterns. Figure 7.8 shows the different occupancy patterns for different buildings as proposed by Dr. Baker and the pattern related to a mosque. Therefore, there is strong need to develop the correction factor value for the distinctive occupancy pattern as related to mosques. The author has suggested a

Table 7.18 Mean ambient temperature below T_{set} in mosque for all months and the calculated night degree hours per month

Months	Mean night temp below T_{set} (°C)	Night ventilation		Night degree hours/ month
		hours/day	days/month	
January	2.71	7	31	588
February	2.71	7	28	531
March	2.35	7	31	510
April	0.53	4	30	64
May	0	0	30	0
June	0	0	31	0
July	0	0	31	0
August	0	0	31	0
September	0	0	30	0
October	0	0	31	0
November	0.53	4	30	64
December	2.46	7	31	533



(27 + 11) / (2 x 7) = 2.71°C

Figure 7.7 The determination of mean night temperature below T_{set} in February.

Table 7.19 First correction factors

Occupancy	Lightweight	Heavyweight
1	1.0	1.0
2	0.9	0.7
3	0.85	0.55
4	0.8	0.4
5 (mosque)	0.80	0.45

Source: Baker, N. (1987). Passive and Low Energy Building Design for Tropical Island Climates, p. 134.

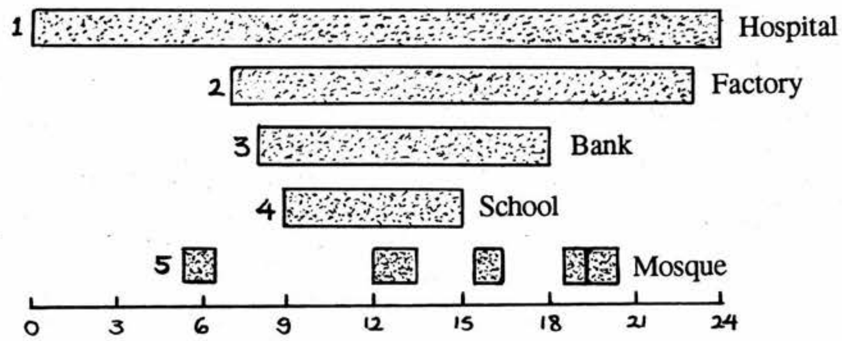


Figure 7.8 Different occupancy patterns including mosque.

correction value for a mosque to be 0.80 for light occupancy and 0.45 for heavy occupancy. This estimation was later discussed and agreed by Dr. Baker[20].

The second correction factor is related to night ventilation. Increased ventilation at night when the ambient temperature is below the building temperature has a cooling effect equal to the full value of ventilation loss. If the building is not occupied during this time, the value of the night ventilation is dependent on the ability of the thermal mass to store "coolth", and how long and how far the occupied period is away from the night cooling period. Similar to the first correction, the second correction factor for a mosque is suggested to be 0.6 under a heavyweight occupancy and 0.25 under a lightweight occupancy (Table 7.20). Both figures were approved by Dr. Baker.

Table 7.20 Second correction factors

Occupancy	Lightweight	Heavyweight
1	1.0	1.0
2	0.60	0.85
3	0.40	0.80
4	0.20	0.50
5 (mosque)	0.25	0.60

Source: Baker, N. (1987). Passive and Low Energy Building Design for Tropical Island Climates, p. 134.

7.2.7 Air conditioning energy consumption reduction

There is difference between the value of useful reductions in cooling loads as related to solar gains, representing a saving in cooling requirement in the conditioned space and the saving in energy which has to be delivered to the plant room. It is this delivered energy that the building users have to pay for, and thus it is the economic and environment costs of this delivered energy in which we are ultimately interested.

Most cooling systems require mechanical power. This power is partly used to run fans which move the cooled air around the building through ducts and in some systems and to move cooled water around the building to local air-cooling units in other systems. Furthermore, this mechanical power is used to drive the refrigeration compressor.

Electric motors are the mechanical power for fans, pumps, and the refrigeration compressors. Other prime movers such as reciprocating diesel or gas engines, or gas turbines are used only in large installations.

In principle, a simple Plant Efficiency Factor can be applied which will indicate the ratio of the Useful Cooling Energy to Delivered Energy[21]. The factors affecting this figure will be as follows:

1) Energy of distribution (known as "parasitic" energy), concerning fan and pump power. This energy is influenced by the duct work design and layout.
2) Distribution losses, i.e. heat gains to the cooled air or water which are not

from the conditioned spaces.

3) Refrigeration efficiency.

Regarding the refrigeration efficiency, a further explanation is needed. Most cooling machines operate as domestic refrigerator, i.e. they are heat pumps. A motor pumps a refrigerant material which changes from gas to a liquid and back to a gas again, through a cycle. At the phase change from liquid to gas, heat is absorbed by the latent heat of evaporation, whilst when the gas is condensed, heat is freed. Thus if the evaporator is situated in the room to be cooled (or more usually in the air stream to be cooled), and the condenser is positioned outside the building, heat is pumped from the inside to outside, thereby offsetting the heat gain to the building.

The mechanical pumping requires energy and this energy depends upon the mechanical efficiency of the system - i.e. friction, etc. and upon the thermodynamic efficiency. Clearly heat is pumped from a cool space to a warm space, and this "pushing heat uphill" requires mechanical energy - the greater the temperature difference, the greater the mechanical energy required.

In typical conditions, the thermodynamic efficiency is much greater than 1. A kW of useful mechanical power will pump about 3 kW of heat from a temperature of, say, 15 °C to one of 35 °C, under typical building conditions. However, the mechanical efficiency and all of the other factors in (1) and (2) will be less than 1.

For simplicity these efficiency factors can be combined into one overall Plant Efficiency Factor. When multiplying the useful reductions in cooling by this factor, it will give us the actual saving in delivered energy[22] i,e, air conditioning energy saved. Typical Plant Efficiency Factors are given in table 7.21.

7.3 CO_2 Emissions reductions

Air conditioning system usually use electricity as an energy source. As discussed before, electricity generated from coal or oil emits relatively high levels of CO_2 emissions. The more electricity is used by a/c systems the larger the amounts of CO_2 is expected at the point of generation.

Table 7.21 - Overall cooling Plant Efficiency

Approximate power input for residential and light commercial cooling requirement

	per kw cooling (kw)
Compressor	0.33 - 0.43
Circulating fan	0.03
Condenser fan	0.04
Total	0.40 - 0.50
Overall system efficiency	2.0 - 2.5

Source: McQuiston, F. , Parker, J., and Johnson, W. (1974). Heating, Ventilating and Air Conditioning. Oklahoma State University.

It was estimated in the UK that for each unit of electricity used by the consumer, the expected amount of CO_2 emitted is 214 Kg per gig joul[23] (table 7.22) , or 0.059 Kg per Kilowatt hour (Kwh = Mega joul / 3.6)[24]. This estimation is conidered to be applicable to Saudi Arabia.

Therefore, emissions of CO_2 as related to reduced air conditioning energy can be calculated directly by multiplying the amounts of air conditioning energy reduced by the amount of CO_2 produced for each kwh of electricity used.

Amounts of CO_2 emissions reduction = E_{ac} x 0.059

0.059 estimated amounts of CO emission per 1 Kwh (Kg)

7.4 CFCs emissions reductions

Air conditioning systems use a mechanical compression refrigeration machines. These compression systems usually use CFCs as refrigerant. Table 7.23 shows the types of CFCs and their weight used in some a/c units. These refrigerants were selected largely on the basis of their performance at the operating temperatures normally found in air conditioning systems. Furthermore, they are safe, being non-flammable and having low toxicities[25]. A large number of these systems are thought to suffer from leakage; emitting these gases directly from the machine (direct emission from the building) to the atmosphere, under four circumstances:

1. Some refrigerant is lost during service work or machine cleaning.

Table 7.22 Carbon dioxide emissions from various fuels used in the United Kingdom

Fuel	At point of combustion in Kg/GJ	Including Processing and distribution in Kg/Gj
Solid fuel	93	97
Natural gas	53	58
Oil	68	79
Electricity	-	214

Source: Henderson. G. (1992). " Building Energy Efficiency and the Greenhouse Effect", Property Journal, June, p. 12-13.

Table 7.23 Types of CFCs and their weights used in some air conditioning units.

Brand	A/C type	Capacity Btu/h	CFC type	CFC weight kg	CFC weight lb-oz
Daikin[d]	Window type	12,000	R22	0.90	
		18,000	R22	1.55	
		22,000	R22	1.82	
Daikin	split floor type	39,000	R22	2.50	
		49,000	R22	3.10	
Carrier[c]	Central	42,000	R22		07-8
		48,000	R22		09-4
		60,000	R22		10-4

[d] Daikin Catalogue (1992). "Split Sky Air", Daikin Industries LTD, Tokyo, pp. 21&24.

[c] Carrier Catalogue (1990). "Single Package Air Conditioners; 50NE", Catalogue No. 525-007, Carrier Corporation, New York, pp. 7&8.

2. Some refrigerant is released together with the unwanted air being trapped or purged from system operating below atmospheric pressure.
3. Some refrigerant is emitted due to catastrophic accident such as incorrect use of the system or its components or external mechanical damage.
4. Slow leak may occur from a detective seal or joint undetected for a long time as the machine will continue operating until a significant amount of the refrigerant has been lost[26].

It is impossible to determine the cause of these losses, or the leakage rates from different types of system. In this study, the fourth source of leak as related to machine operation will be considered as the main source of CFCs emission and any cut in machine operation will definitely reduce the amount of refrigerant emission..

No data on leakage rates from air conditioning systems has been published[27]. A BRE (Building Research Establishment) survey on eight air conditioned buildings in 1990 showed that annual refrigerant losses from air conditioning systems ranged from under 2% to 13% of the total system charge, with an additional total loss of refrigerant charge occurring in some buildings once every 5 to 10 years. From the survey carried out in some of Jeddah's air conditioned mosques, it was found that a refrigerant charging processes are carried out every 5 to 7 years. Therefore, the annual refrigerant loss from air conditioning systems in existing mosques ranges from 14% to 20% of the total system charge. The annual and monthly CFCs emissions from air conditioning unit is calculated as follows:

Expected annual CFCs emission from each a/c unit =

$$\frac{\text{Total refrigerant charge (normally stated in the catalogue in Kg)}}{\text{Numbers of years when the full refrigerant charge is carried out}}$$

Monthly CFCs emissions from each a/c unit =

$$\frac{\text{Estimated annual CFCs emission from each a/c unit}}{\text{11 months (a/c not used in January)}}$$

In calculating the amounts of CFCs emissions reduction the following equations are adopted:

Amounts of CFCs emissions reduction:

a. The monthly % of air conditioning energy reduction =

Monthly E_{ac} reduced / Monthly E_{ac} initial

b. Monthly no. of a/c units reduced = Monthly no of a/c units monthly used x the monthly air conditioning energy reduction percentage

b. Amounts of CFCs emissions reduction =

Number of a/c units reduced x monthly CFCs emissions

7.5 Money saved

The amount of money saved can be calculated from the amounts of air conditioning energy reduced and the price of electricity. Table 7.24 shows the price of electricity in Saudi Arabia. The prices are classified into three categories based on the scale of consumption. Mosques in the Kingdom normally pay the lowest rate (0.05

SRi/ Kwh or 0.008 Sterling) whatever the level of energy consumed. The adopted formula is as follows:

Money saved = Air conditioning energy saved x 0.05

7.6 Payback period and cost effectiveness

At this stage it is very important to find out (i) the costs of purchasing and installation of the measures proposed, mainly insulation materials, in contrast with their air conditioning energy, CO_2 emissions, and CFCs emissions savings (ii) and the cost effectiveness of these measures.

It is important to gather a reasonable knowledge about the various prices of the building materials, the labour, and the building construction in Saudi Arabia in order find out the costs of purchasing and installation of the proposed measures. A brief and quick estimate of construction cost, building materials prices, and labour prices is included in the following section.

There are two procurement methods for the construction of mosque building in Saudi Arabia. The first way is the turn key contract where the contractor constructs the building from the foundation up complete with services installation and finishes and hands the key to the owner, costing around 1500 to 2000 Saudi Riyals (250-333 Sterling pounds) per square metre. The other way is called the skeleton contract where the contractor constructs only the main structural elements of the building including

Table 7.24 Electricity sale prices in Saudi Arabia

Category	Energy consumption in Kwh	Cost in (Sri)	Cost in (£)
1	1 to 4000	0.05	0.008
2	4000 to 6000	0.08	0.013
3	6001 and over	0.15	0.025

Source: Subscribers Directory, The Saudi Consolidated Company for Electricity in The Western Province, undated, p. 10

walls costing 600 to 800 SRi (100-130 Sterling pounds) per square metre. The services installation and finishing trades are completed by individual labour employed by the owner. As far as the managing ways of the construction of additional building elements to the existing building elements is concerned, both ways are adopted.

Regarding the individual man-power prices, there are daily prices and unit prices; the daily prices are typically 40 SRi (£6.5) for unskilled labour and 60 SRi (£10) for skilled labour. The unit prices vary considerably upon the manpower and the owner.

Finally, the prices of the main building materials are summarised in table 7.25. As far as the cost of the proposed walls and roofs are concerned, the estimated costs are shown in table (7.26). These prices are based on personal interviews with various building contractors, owners, and architectural offices in Jeddah in 1993.

It is important, however, to study the cost effectiveness of the proposed passive cooling measures, verifying the cost of purchasing and installation with their savings. The simple way of calculating the cost effectiveness of the proposed solutions is the pay-back calculation. This is the initial cost divided by the annual energy , and it measures the number of years it takes for a project to pay for itself. Similarly, the concept can be applied on the related emissions savings verifying the amounts of emissions produced for purchasing, manufacturing, and installing the proposed measures with their emission savings. Namely, the author has limited the analysis to the cost effective analysis as regard to energy due to the lack of information on emissions

Table 7.25 Prices of some building materials in Saudi Arabia in 1993.

Hollow concrete block	1 SRi/block
Cement	12 SRi/bag
Coarse aggregate	17 SRi/m3
Fine aggregate	7 SRi/m3
Plastering (indoor)	7 SRi/m2
(outdoor)	22 SRi/m2
Paint	8 SRi/m2
Tile	30 SRi/m2
Tiles installation	15-20 SRi/m2
Calcium silicate block	1.2 SRi/block
Extruded polystyrene (25,50,75mm)	27 SRi/m2

Table7.26 Estimated cost of the proposed modifications to existing roof and walls (Sri/m^2).

Roof	Cost (Sri)	Wall	Cost (SRi)
0	40	0	25
1	70	1	52
2	97	2	52
3	97	3	52
4	97	4	67
5	76	5	67
6	76	6	67
7	76	7	25

concerning the manufacturing, installation, and purchasing processes involved with these proposed measures.

The basis for selecting the most cost effective in terms of air conditioning energy consumption measures is the pay back period which will be developed using the following formula:

Pay back period =

$$\frac{\text{The cost of purchasing/installing one square metre of the proposed measure}}{\text{Money saved per square metre}}$$

7.3 The development of worksheets

Four worksheets are developed to assist in the calculation method (see worksheets). An explanatory notes for using this worksheet is discussed in the next section.

7.3.1 Explanatory notes for using the worksheets

A. Reduction of external solar gain worksheet

This calculates the change in solar gain made on the external surface and conducted into the interior:

a. A need for more than one worksheet is expected when several options or different zones within a building are to be investigated. Therefore, the numbering of worksheet is required.

A. MONTHLY ENERGY BASE CALCULATION WORKSHEET

Monthly Base Energy Calculation								
Appliances	Sound system	Lights	Fans	Water cooler	Vacuu. cleane r			
No. of appliance								
Monthly time of use	32.47-45.25	71-185	117-154.4	117-154.4	6-10			
Mean elec. consump	0.3	0.1	0.1	0.2	0.2			
Monthly elec consu								
Total monthly load								

A. REDUCTION OF EXTERNAL SOLAR GAINS WORKSHEET

	Description of SHF reductions	radiation affected
1		
2		
3		

	SHF ⇓			Month ⇒		J	F	M	A	M	J	J	A	S	O	N	D
N or (NE)		D	D	D	D												
	O			change													
	N			Area													
	ch			reduc.													
E or (SE)		D	D	D	D												
	O			change													
	N			Area													
	ch			reduc.													
S or (SW)		D	D	D	D												
	O			change													
	N			Area													
	ch			reduc.													
W or (SW)		D	D	D	D												
	O			change													
	N			Area													
	ch			reduc.													
ROOF		D	D	D	D												
	O			change													
	N			Area													
	ch			reduc.													

cooling load reduction													
Actual cooling load red.	.80-.45												
Air cond. energy reductn.	2-2.25												

Kwh	initial air cond. energy												
	% of reduced a/c energy												

CO_2	from initial a.cond. energy												
(0.059)	from reduced a/c energy												
kg/kwh	% CO_2 reduction												

CFCs	monthly a/c units used												
kg/m	% of a/c units reduced												
	reduced no. of a/c units												
	monthly total emissions												
	monthly reduced emission												
	% of reduced emissions												

Money	from initial a.cond. energy												
(0.05)	from reduced a/c energy												
Sri/Kwh	% money reduction												

B. REDUCTION OF INTERNAL SOLAR GAINS WORKSHEET

	Description of SG reductions	radiation affected
1		
2		
3		

	SHF		⇓	Month ⇒	J	F	M	A	M	J	J	A	S	O	N	D
N or (NE)		D	D	D D												
	O			change												
	N			Area												
	ch			reduc.												
E or (SE)		D	D	D D												
	O			change												
	N			Area												
	ch			reduc.												
S or (SW)		D	D	D D												
	O			change												
	N			Area												
	ch			reduc.												
W or (SW)		D	D	D D												
	O			change												
	N			Area												
	ch			reduc.												
horiz.		D	D	D D												
	O			change												
	N			Area												
	ch			reduc.												

cooling load reduction												
Actual cooling load red.	.80-.45											
Air cond. energy reductn.	2-2.25											

Kwh	initial air cond. energy												
	reduced air cond. energy												
	% of reduced a/c energy												

CO_2	from initial a.cond. energy												
(0.059)	from reduced a/c energy												
kg/kwh	% CO_2 reduction												

CFCs	monthly a/c units used												
kg/m	% of a/c units reduced												
	reduced no. of a/c units												
	monthly total emissions												
	monthly reduced emission												
	% of reduced emissions												

Money	from initial a.cond. energy												
(0.05)	from reduced a/c energy												
Sri/Kwh	% money reduction												

C. REDUCTION OF CONDUCTIVE GAINS WORKSHEET

	elements	U-value			area		change in conductance
		original	new	change			
1							
2							
3							
4							
5							
			total change in conductance in W/°C				

T_{set}													
month		J	F	M	A	M	J	J	A	S	O	N	D
mean T_{amb}													
diurnal swing curve													
increment over mean during occupancy													
mean temperature difference													
occupancy	hrs/day												
	days/m												
degree hrs/month													
total change in conductance W/°C													
change in conductive gains 1													
Actual cooling load red.	.80-.45												
Air cond. energy reductn.	2-2.25												

Kwh	initial air cond. energy												
	% of reduced a/c energy												

CO_2	from initial a.cond. energy												
(0.059)	from reduced a/c energy												
kg/kwh	% CO_2 reduction												

CFCs	monthly a/c units used												
kg/m	% of a/c units reduced												
	reduced no. of a/c units												
	monthly total emissions												
	monthly reduced emission												
	% of reduced emissions												

Money	from initial a.cond. energy												
(0.05)	from reduced a/c energy												
Sri/Kwh	% money reduction												

D. NIGHT VENTILATION WORKSHEET

night vent. rate	building volume		night vent. conductance
		x 0.33	

			J	F	M	A	M	J	J	A	S	O	N	D
mean T_{amb}														
diurnal swing curve														
mean night temp below T_{set}														
night ventilation		hrs/day												
		days/m												
night degree hrs/month														
night vent conductance														
night ventilation loss.														
Actual cooling load red.		.25-.60												
Air cond. energy reductn.		2-2.25												
Kwh	initial air cond. energy													
	% of reduced a/c energy													
CO_2	from initial a.cond. energy													
(0.059)	from reduced a/c energy													
kg/kwh	% CO_2 reduction													
CFCs	monthly a/c units used													
kg/m	% of a/c units reduced													
	reduced no. of a/c units													
	monthly total emissions													
	monthly reduced emission													
	% of reduced emissions													
Money	from initial a.cond. energy													
(0.05)	from reduced a/c energy													
Sri/Kwh	% money reduction													

b. Describe the measure related to the reduction of SHF.

c. Decide whether shading or other measures affects direct and diffuse, or direct only and for which orientation.

d. Choose between north, south orientation or NE-SW orientation. Since most buildings are orthogonal this will normally be sufficiently accurate.

e For the appropriate orientation, enter the original, new and change of SHF. Change of SHF is (original - new). If more than one SHF reduction is entered at (b), these have to be combined to give one value for each Radiation Total.

f. Enter monthly total radiation values from table 7.4 as related to the specific ground reflectance value. It could be different for different orientations.

g. Multiply the Radiation Totals entered by the Changes in SHF.

h. From building data, enter the area of the surface to which change of the SHF applies. For instance, if an east-facing wall has been painted white, enter the area of the east wall.

i. Multiply the changed radiation totals and the area giving the total change for each surface (shaded boxes).

j. Sum these shaded boxes to get the total monthly cooling load reduction.

k. Multiply the monthly reduction in gains by the correction factor f_l to get useful reduction.

l. Divide the actual cooling load reduction by 2.25 to get the actual amount of reduction in air conditioning energy (i.e. reduction in delivered energy for cooling).

m. Enter the values of the monthly air conditioning energy obtained before.

n. Calculate the reduction percentage in monthly air conditioning energy.

o. Calculate the amount of CO_2 emissions as related to both actual air conditioning energy used and air conditioning energy reduced and identify the reductions' percentages of CO_2 on monthly basis.

p. Define the number of a/c used each month. Use the same reduction percentage achieved in air conditioning energy to find the number of a/c that can be eliminated. Calculate the CFCs emissions before and after the reduction and find out the monthly reduction percentages of CFC emissions.

B. Reduction of Internal solar gain worksheet

This calculates the change in solar gains entering the building through openings. It is similar to worksheet described before except that the Solar Gain Factor (SG) is used instead of the Solar Heat Gain Factor (SHF). The SG can be described as the ratio of the solar energy absorbed in the prayer hall to that incident upon the opening of the window. The change of SG can be due to reduction in transmittance value of the glass or shading.

C. Reduction of conductive gain worksheet

The worksheet is designed to calculate the change in heat gain through the fabric. This heat gain is influenced by:

1. The conductance or U-value of the external envelope.

2. The temperature difference between the inside and outside.

A change in the heat gain might be brought about by a change of (1) or (2) or both. A change of U-value of the external envelope of existing mosques is of most concern in this research, therefore, the second option will not be discussed.

a. Give reference number for successive measures.

b. List the elements to which reducing measures have been applied.

c. Enter the original, new and change in U-value.

d. Enter the areas associated with the elements and U-values. Multiply the change in U-values and areas together to get the change in conductance. Sum the column to get the total change in conductance.

e. Enter the Set Temperature T_{set} (target temperature for the air conditioning) that applied during occupancy.

f. Enter mean monthly ambient temperature from Jeddah climatic data.

g. Choose the nearest diurnal swing curve after inspecting monthly maximum and minimum temperatures and enter the value.

h. Determine the temperature decrement (over mean ambient) during occupation by using appropriate curve. Use the actual occupancy period in the mosque.

i. Calculate and enter the difference between the T_{set} and the mean temperature during occupation as follows;

$$T_{(mean\ ambient)} + \text{increment} - T_{set}$$

j. Enter actual occupancy hours per day as well as days per month. Then for each month multiply by mean temperature difference to get degree hours per month.

k. Multiply degree hours by change in conductance to obtain monthly change in conductive gain.

l. Multiply the monthly conductive gains by the correction factor f1 to get useful reduction.

m. Divide the useful reduction in conductive gains by 2.25 to get the actual amount of reduction in air conditioning energy (i.e. reduction in delivered energy for cooling).

n. Enter the values of the monthly air conditioning energy obtained before

o. Calculate the reduction percentage in monthly air conditioning energy.

p. Calculate the amount of CO_2 emissions as related to both actual air conditioning energy used and air conditioning energy reduced and identify the reductions' percentages of CO_2 on monthly basis.

q. Define the number of a/c used each month. Use the same reduction percentage achieved in air conditioning energy to find the number of a/c that can be eliminated. Calculate the CFCs emissions before and after the reduction and find out the monthly reduction percentages of CFC emissions.

D. Night ventilation worksheet.

This worksheet is concerned with a heat loss from existing mosques usually during the unoccupied period when the ambient temperature is below the temperature in the mosque.

a. Calculate the conductance of night ventilation for estimates of achieved night ventilation rates.

b. Enter T_{set} for occupancy period. As this temperature may not occur in the mosque during the night ventilation period the difference is taken account of by the correction factor (f_2) suggested.

c. Use the Temperature Calculator in order to:

   1. Determine night ventilation period. This period is defined as the period of which the ambient temperature is below T_{set} and this can be directly read off from the calculator.
   2. Determine mean ambient temperature during this period by the following steps:
      a. Draw the mean ambient temperature and the T_{set} on the grid.
      b. Choose the appropriate swing curve and count the squares between the curve and the T_{set} line.
      c. Calculate the increment (or rather decrement) by dividing the number of squares by twice the night vent hour.

d. Enter night vent hour as determined above, bearing in mind that this will vary on a monthly basis and may be zero for some months. Enter occupied days per month.

e. Multiply night degree hours by night ventilation conductance to give night vent loss for each month.

f. Multiply the night vent loss by the correction factor f_2 to get useful reduction.

g. Divide the actual cooling load reduction by 2.25 to get the actual amount of reduction in air conditioning energy (i.e. reduction in delivered energy for cooling).

i. Enter the values of the monthly air conditioning energy obtained before.

j. Calculate the reduction percentage in monthly air conditioning energy.

k. Calculate the amount of CO_2 emissions as related to both actual air conditioning energy used and air conditioning energy reduced and identify the reductions' percentages of CO_2 on monthly basis.

l. Define the number of a/c used each month. Use the same reduction percentage achieved in air conditioning energy to find the number of a/c that can be eliminated. Calculate the CFCs emissions before and after the reduction and find out the monthly reduction percentages of CFC emissions.

In this chapter, the calculation methods related to the proposed strategy and the improvement measures of insulation U-values, shading and night ventilation have been discussed. The methods calculate the potential reductions in air conditioning energy consumption, the atmospheric pollutants emissions levels and money as wll as the cost effective analysis. In the coming chapter, the intention is to study the applications of the proposed strategy and the improvement measures defined (Chapters Three and Six) in nine selected case study mosques (Chapter Five) estimating their potential savings that can be achieved with the use of the calculation methods discussed in Chapter Seven.

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CHAPTER EIGHT: APPLICATIONS OF THE PROPOSED PASSIVE COOLING STRATEGY AND PASSIVE COOLING IMPROVEMENT MEASURES AND THEIR POTENTIAL SAVINGS

8.1 Introduction

The main objectives of this chapter are to (1) study the applications of the proposed passive cooling strategy and the proposed improvement measures in nine selected mosques (Chapter Five) and (2) to calculate their potential savings in air conditioning energy, money and CO_2 and CFCs emissions by using the methods discussed in Chapter Seven. In each mosque category three subjects will be highlighted; (1) mosque conditions, (2) energy and cooling systems used and (3) the strategy and the measures potential savings achieved. The last part of the chapter discusses the strategy and the improvement measures performances in all mosque categories as well as the use of the measures performance results in the development of the potential savings tables which can be used by the architect to predict the potential savings of these measures when applied to any mosque. The chapter ends by discussing the estimation of the potential savings of these proposed strategy and measures at the city level and their contribution to the national air conditioning energy consumption and CO_2 and CFCs emissions levels.

8.2 The measures applications in mosques and their potential savings calculations

8.2.1 The small district mosques

8.2.1.1 Case study I-A (Zaid Al-khair Mosque)

Zaid Al-khair mosque has been selected to represent the first category of the surveyed mosque characterised by lowest air conditioning energy consumption. It is located in a medium-density community in part of an open plot left for public services. The mosque and its services are totally isolated from the neighbouring buildings. The mosque is surrounded by a paved open space on all sides.

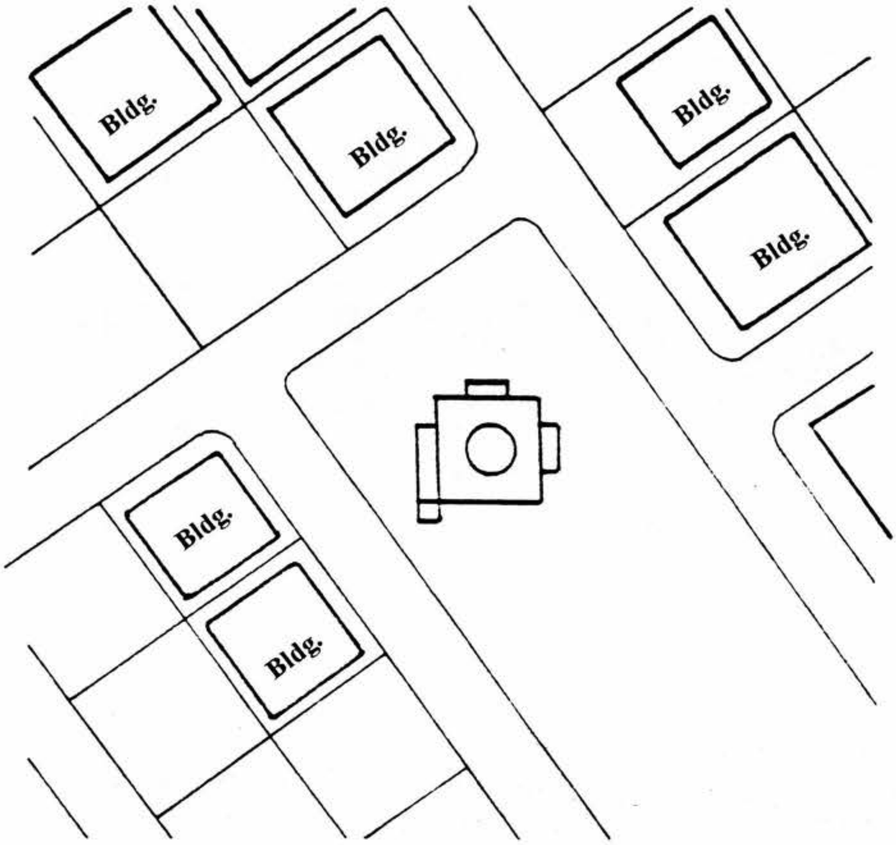
8.2.1.1.1 Mosque conditions

It is 10 years old. It has two storeys; (i) the main male prayer hall in the ground level with two storey high and an upper female prayer hall in the mezzanine covering only one third of the mosque. An isolated structure for ablution is located far from the mosque and has an area of 50 square metres. Areas around the mosque are paved and there is no plantation (figures 8.1 A and B).

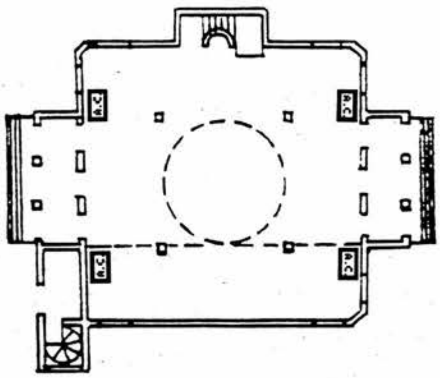
The mosque can accommodate 303 worshippers of different ages. The mosque is always full in Friday prayer and only partly occupied (one third) during daily prayers. The managers of this mosque are educated. The plot gross area is approximately 1806 square metres and the actual built area of the mosque is 272 square metres. A summary of the mosque's details is listed in table 8.1.

8.2.1.1.2 Energy, active and passive cooling systems used

The energy most commonly used in the region and all over the Kingdom is electricity. It is used to run the cooling system and the appliances. The average monthly air conditioning energy consumption and the number of air conditioners involved are shown in Table 8.2. The average annual energy consumption for this mosque is 23631 Kwh of which 15231 Kwh as energy for cooling the mosque



Site Plan



Plan

Figure 8.1 (A) The urban configuration of Zaid Al-Khair mosque, showing the mosque in relation to its neighbours (upper) and the ground floor plan of the mosque (lower).

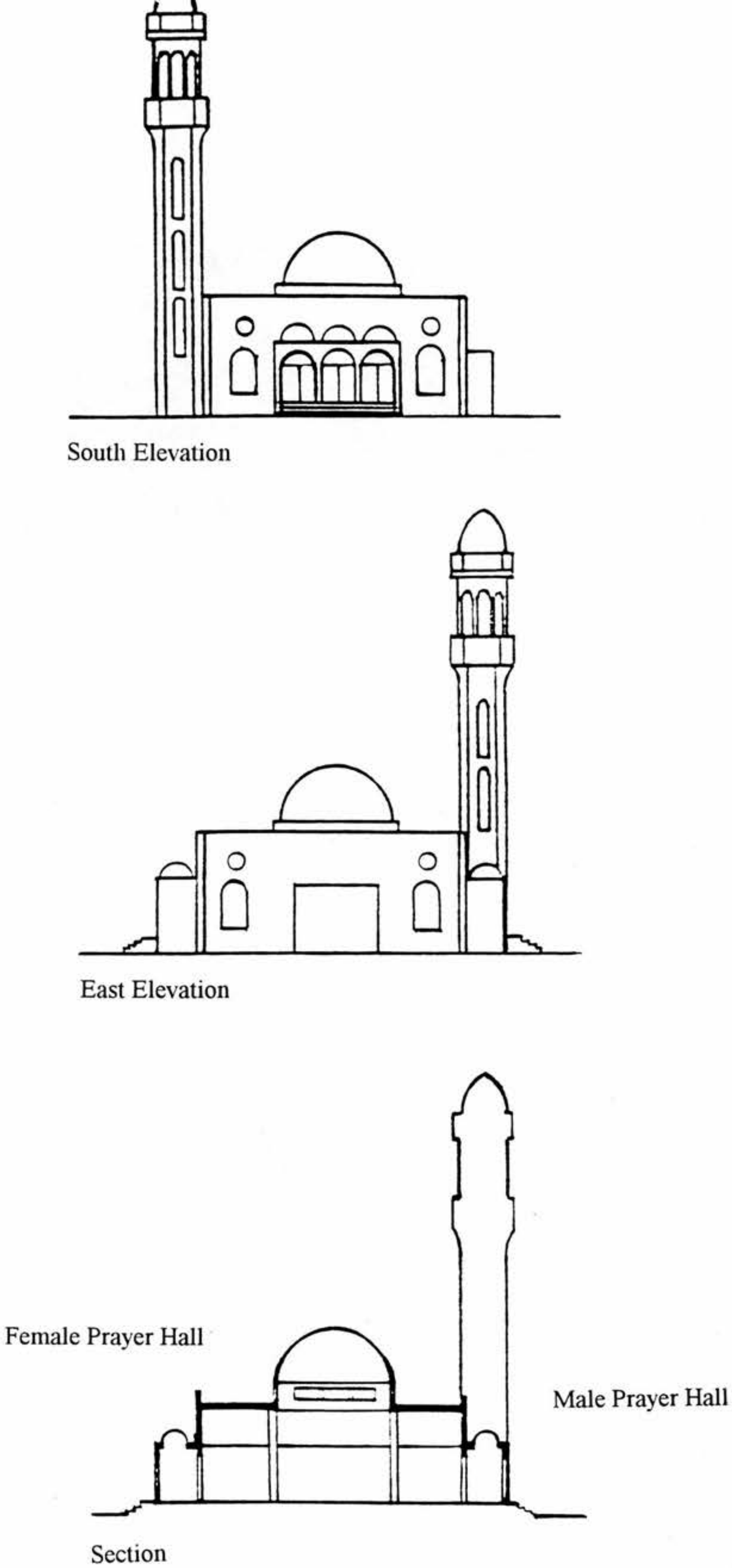


Figure 8.1 (B) South and east elevations and section of Zaid Al-Khair mosque.

Table 8.1 Some details of Zaid mosque used in the calculation.

ITEMS	Zaid Al-Khair
Dimensions	mosque
Plot size	1806 sq. m
Mosque area	272 sq. m
Mosque volume	1502 cub. m
Number of Worshippers	303 person
Mosque services area	50 sq. m
U- Value (W/m^2 k)	
. External walls: 210 mm thick concrete block with 50 mm sand cement mortar and 20mm marble tiles	1.002
. Glazing: Single glazed windows	5.6
. Roof: Tiled reinforced concrete flat roof with plastered ceiling	2.922
. Floor: Reinforced concrete floor in contact with the earth, tiled and carpeted	1.13
Internal temperature	25°C
External temperature	36°C
Areas	
. Exposed prayer hall's walls to the outdoor environment	240 sq. m
. Glazing	15.75 sq. m
. Flat roof	200 sq. m

Table 8.2 Monthly air conditioning energy consumption (Kwh) and the number of air conditioners used in Zaid mosque.

Month	Air conditioning energy (Kwh)	Numbers of A/C units
January	0	0
February	588	3
March	764	3
April	944	4
May	1070	4
June	3040	5
July	3320	5
August	1769	4
September	1369	4
October	1225	4
November	712	3
December	430	3

mechanically and the remaining 8400 Kwh as energy base. The annual average cooling energy consumption for one cubic metre is estimated to be 10.14 Kwh emitting 0.59 Kg of CO_2 gas.

The different appliances used in this mosque are: two 1.8 cubic feet water coolers, one sound amplifier system, 11 ceiling fans, air conditioners, and 40 lights.

This mosque is cooled mechanically by using active cooling system and ceiling fans. 5 units of 50000 Btu cooling capacity split type air conditioning system is used. The systems are put on 20 minutes prior to the calling of the prayer and shut down once the prayer has finished. The systems are not used for the whole month of January. The air conditioners are always left without service and reinjected with refrigerants every 5 to 6 years. The cooling systems are used during the daily and Friday prayers, teaching the Holy Quran, and special lectures occasionally delivered (2-3 times) on monthly basis.

The managers of this mosque improved the infiltration in the mosque by keeping the cold air inside and prevent the hot air penetrating from the outside through the proper closure of windows and holes and cracks on walls. Furthermore, they used natural ventilation twice a day before Duhur and Asr prayers for 10 minutes. Finally, they use natural ventilation during the month of January as the weather allows.

8.2.1.1.3 The proposed strategy and measures' performances

The results of the proposed strategy and measures potential savings are listed in Tables 8.3 and 8.4 (A, B, C, D, E and F) respectively.

Table 8.3 The estimated potential reductions of the proposed passive cooling strategy in Zaid mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Thermal mass and air movement	12110.93	714.54	605.54	79.51	2.03	86.34	8.063	0.475	.403	.069

Table 8.4 (A) The estimated potential reductions of the proposed measure of night ventilation in Zaid mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Night Ventilation	656	38.70	32.8	4.3	.112	4.7	.436	0.025	0.021	.0036

Table 8.4 (B) The estimated potential reductions and payback periods of the proposed measure of complete shading existing windows in Zaid mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost 1 m^2 (SRi)	Pay back period (years)
Shading Windows	2735	161.36	136.75	17.95	0.28	11.9	173.59	10.229	8.67	1.495	65	7.5

Table 8.4 (C) The estimated potential reductions and payback periods of the proposed wall measures in Zaid mosque

Wall Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	1.770	15231											
0	0.926	2056	121.3	102.8	13.49	0.000	0.00	8.567	0.505	0.428	0.073	25	58
1	0.541	2907	171.5	145.35	19.09	0.280	11.90	12.115	0.714	0.605	0.104	52	85
2	0.380	3259	192.2	162.95	21.40	0.392	16.60	13.582	0.801	0.679	0.117	52	76
3	0.293	3487	205.7	174.35	22.89	0.448	19.00	14.530	0.857	0.726	0.125	52	71
4	0.679	2576	151.9	128.80	16.91	0.056	2.30	10.733	0.633	0.536	0.092	67	125
5	0.444	3131	184.7	156.55	20.55	0.336	14.20	13.045	0.769	0.652	0.112	67	102
6	0.330	3421	201.8	171.05	22.46	0.448	19.04	14.257	0.841	0.712	0.122	67	94
7	0.664	2608	153.8	130.4	17.12	0.056	2.30	10.870	0.641	0.543	0.093	25	46

Table 8.4 (D) The estimated potential reductions and the payback periods of the proposed roof measures in Zaid mosque

Roof Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	2.832	15231											
0	1.096	4183	246.7	209.15	27.46	0.504	21.4	20.917	1.234	1.045	0.180	40	38
1	0.892	4742	279.7	237.10	31.13	0.560	23.8	23.713	1.399	1.185	0.204	70	59
2	0.681	5256	310.1	262.80	34.45	0.560	23.8	26.284	1.550	1.314	0.226	97	73
3	0.444	5773	340.6	288.65	37.79	0.613	26.1	28.869	1.703	1.443	0.248	97	67
4	0.330	6113	360.6	305.65	40.13	0.613	26.1	30.566	1.803	1.528	0.263	97	63
5	0.794	4977	293.6	248.85	32.67	0.560	23.8	24.886	1.468	1.244	0.214	76	61
6	0.490	5722	337.5	286.10	37.56	0.613	26.1	28.610	1.687	1.430	0.246	76	53
7	0.354	6052	357.0	302.60	39.74	0.613	26.1	30.264	1.785	1.513	0.260	76	50

Table 8.4 (E) The estimated percentages of air conditioning energy reductions of the proposed measures in Zaid mosque

		R0	R1	R2	R3	R4	R5	R6	R7
		27.46	31.13	34.45	37.79	40.13	32.67	37.56	39.74
W0	13.49	40.95	44.62	47.94	51.28	53.62	46.16	51.05	53.23
W1	19.09	46.55	50.22	53.54	56.88	59.22	51.76	56.65	58.83
W2	21.40	48.86	52.53	55.85	59.19	61.53	54.07	58.96	61.14
W3	22.89	50.35	54.02	57.34	60.68	63.02	55.56	60.45	62.63
W4	16.91	44.37	48.04	51.36	54.7	57.04	49.58	54.47	56.65
W5	20.55	48.01	51.68	55	58.34	60.68	53.22	58.11	60.29
W6	22.46	49.92	53.59	56.91	60.25	62.59	55.13	60.02	62.2
W7	17.12	44.58	48.25	51.57	54.91	57.25	49.79	54.68	56.86

Table 8.4 (F) The estimated reductions and the payback periods under various combinations of modified roof and walls (namely giving higher saving percentages in air conditioning energy).

Roof Type	Wall Type	U- value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
4	3	0.623	9923	585	496.15	63.00	1.456	61.0	45.096	2.660	2.254	0.388	149	66
7	3	0.647	9860	581	493.00	62.60	1.456	61.0	44.794	2.642	2.239	0.386	128	57
4	6	0.660	9854	581	492.70	62.50	1.400	59.5	44.823	2.644	2.241	0.386	164	73
7	6	0.684	9792	577	489.60	62.20	1.400	59.5	44.524	2.626	2.226	0.383	143	64
4	2	0.710	9687	571	484.35	61.50	1.400	59.5	44.148	2.604	2.207	0.380	149	67
7	2	0.734	9625	567	481.25	61.10	1.400	59.5	43.849	2.587	2.192	0.378	128	58
3	3	0.737	9553	563	477.65	60.60	1.400	59.5	43.399	2.560	2.169	0.374	149	68
4	5	0.774	9553	563	477.65	60.60	1.400	59.5	43.608	2.572	2.180	0.375	164	75
6	3	0.783	9517	561	475.85	60.45	1.400	59.5	43.140	2.545	2.157	0.371	128	59
7	5	0.798	9492	560	474.60	60.29	1.400	59.5	43.312	2.555	2.165	0.373	143	66
3	6	0.774	9485	559	474.25	60.25	1.400	59.5	43.126	2.544	2.156	0.371	164	76
6	6	0.820	9449	557	472.45	60.02	1.344	57.1	42.867	2.529	2.143	0.369	143	66

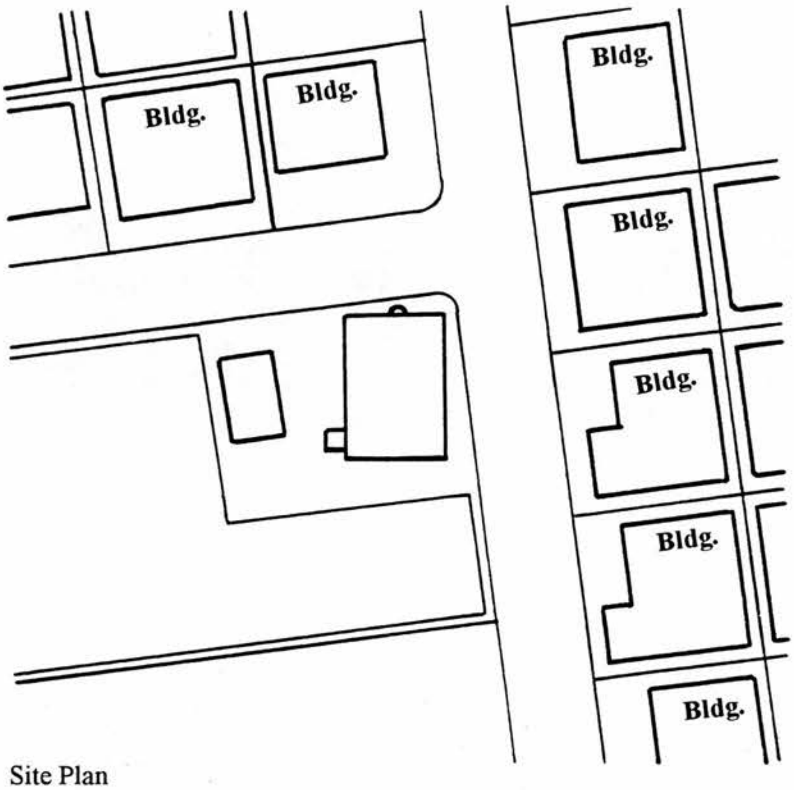
8.2.1.2 Case study I-B (Al-Majd Mosque)

This case study represents the first category (Small District Mosque) of our surveyed mosques which has a moderate air conditioning energy consumption level. The mosque is a one-storey building. It is surrounded by two local streets from the south and east. A large parking plot surrounds the mosque from west and north. With such types of surrounding, heat environment around the mosque is expected to increase.

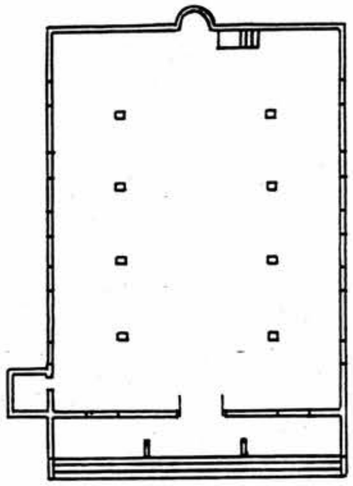
8.2.1.2.1 Mosque condition

The mosque is located in Al-Rawdah residential district, and is set isolated from the neighbouring buildings and the Imam and Muaddin quarter. The mosque consists of a ground level floor used as male prayer hall. The mosque is mainly surrounded by paved open spaces which increase the solar intensity around the mosque. Only few number of trees exist in the area (see figures 8.2 A and B).

The mosque can accommodates 312 worshippers. Only a fourth of the mosque is usually occupied during Duhur and Asr prayers, fifth in Fajr prayer, and full in Magrib, Isha'a and Friday prayers. The gross plot area is approximately 5000 square metres. The net built area is 300 square metres for the mosque, 50 square metres for the ablution service, and 100 square metres for the residential quarter. A 4550 square metres area is left as open area and parking lot. A summary of the mosque's details is listed in Table 8.5.

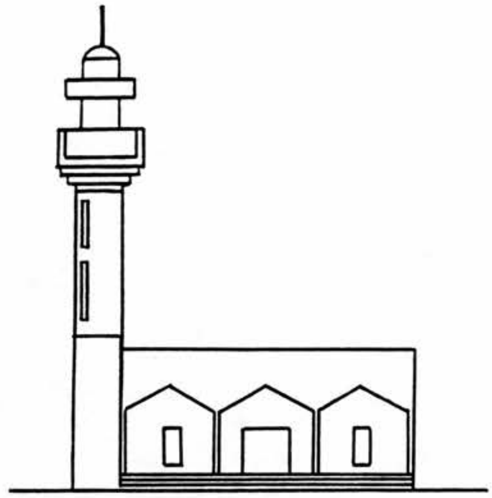


Site Plan

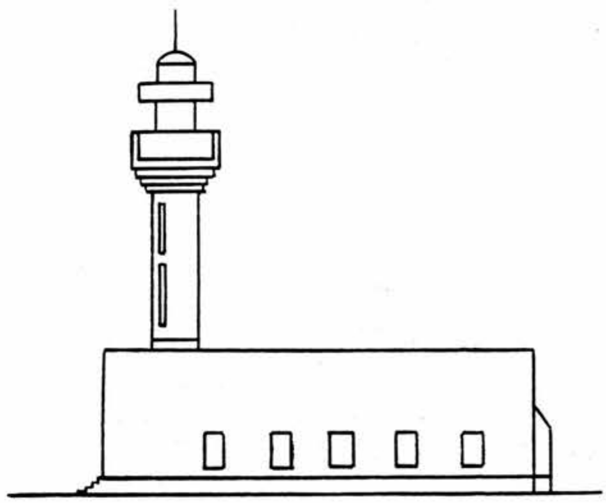


Plan

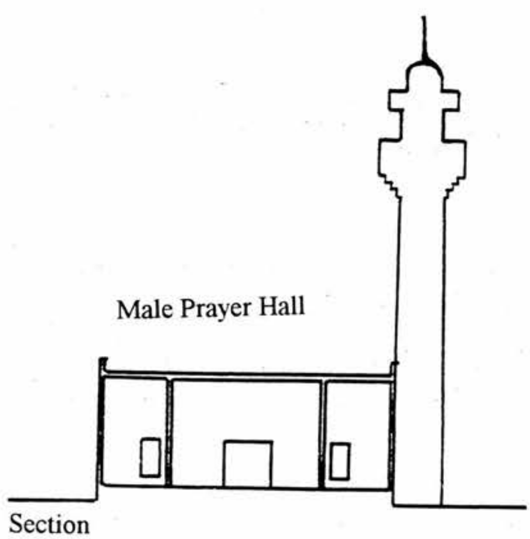
Figure 8.2 (A) The urban configuration of Al-Majd mosque, showing the mosque in relation to its neighbours (upper) and the ground floor plan of the mosque (lower).



West Elevation



South Elevation



Section

Figure 8.2 (B) The south and west elevations and section of Al-Majd mosque.

Table 8.5 Some details of Majd mosque

ITEMS	Al-Majd
Dimensions	mosque
Plot size	5000 sq. m
Mosque area	310 sq. m
Mosque volume	1862 cub. m
Number of worshippers	312 person
Mosque services area	150 sq. m
U- Value (W/m^2 k)	
. External walls: 210 mm thick concrete block with 50 mm sand cement mortar and 20mm marble tiles	1.002
. Glazing: Single glazed windows	5.6
. Roof: Tiled reinforced concrete flat roof with plastered ceiling	2.922
. Floor: Reinforced concrete floor in contact with the earth, tiled and carpeted	1.13
Internal temperature	24°C
External temperature	37.5°C
Areas	
. Exposed prayer hall's walls to the outdoor environment	411 sq. m
. Glazing	19.2 sq. m
. Flat roof	300 sq. m

8.2.1.2.2 Energy, active and passive cooling systems used

The energy used in this mosque is not different from the common energy used throughout the whole Kingdom. The energy used in this mosque is electricity and it is used for the cooling systems and appliances. The average monthly air conditioning energy consumption and the number of air conditioners involved are shown in Table 8.6. The average annual energy consumption for this mosque is about 52820 Kwh where 47420 Kwh is consumed as air conditioning energy. The remaining 5400 Kwh is used by the other appliances. The annual average air conditioning energy consumption is approximately 25.46 Kwh per cubic metre which is responsible for emitting 1.5 Kg of CO_2 gas. The appliances found in this mosque are two water coolers of 1.8 cubic feet, 50 lights, sound amplifier, and air conditioners.

Six units (cooling capacity 50000 Btu) split type air conditioning systems are installed. The system is not usually serviced and is commonly reinjected with refrigerant gas every 5 to 6 years. The system is normally puts on 20 minutes prior to the call of the prayer and shut down 15 to 30 minutes after the prayer has finished. The system is used during the daily and Friday prayers, teaching the Holy Quran and two lectures lasts for 30 minutes each on monthly basis. The high energy consumption sometimes encourages people to put some effort into saving energy, money and the environment by emitting less toxic gases. Unfortunately, the managers of this mosque did not make a noticeable effort partly because they can afford to pay for it. They restricted their effort in reducing infiltration in the mosque and using normal glass protected with poor design sun breakers. Furthermore, they use natural ventilation two to three times a month for 30 minutes after the Friday prayer.

8.2.1.2.3 The proposed strategy and measures' performances

The results of the proposed strategy and measures potential savings are listed in Tables 8.7 and 8.8 (A, B, C, D, E and F) respectively.

Table 8.6 Average monthly air conditioning energy consumption (Kwh) and the number of air conditioners used in Majd mosque.

	Air conditioning energy (Kwh)	Numbers of A/C units
January	0	0
February	1800	3
March	2223	4
April	2579	4
May	4792	5
June	6886	6
July	7237	6
August	7144	6
September	6121	6
October	4222	5
November	3171	4
December	1245	3

Table 8.7 The estimated potential reductions of the proposed passive cooling strategy in Majd mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Thermal mass and air movement	38607.13	2277.82	1930.35	81.41	2.504	85.47	20.730	1.223	1.036	0.178

Table 8.8 (A) The estimated potential reductions of the proposed measure of night ventilation in Majd mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Night Ventilation	813	47.96	40.65	1.71	0	0	0.436	0.025	.021	.003

Table 8.8 (B) The estimated potential reductions and payback periods of the proposed measure of complete shading existing windows in Majd mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost 1 m^2 (SRi)	Pay back period (years)
Shading Windows	3099	182.89	154.99	6.537	0	0	161.45	9.518	8.058	1.385	65	8.06

Table 8.8 (C) The estimated potential reductions and payback periods of the proposed walls in Majd mosque

Wall Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	1.770	47420											
0	0.926	3527	208	176.3	7.43	0	0	8.57	0.505	0.428	0.073	25	58
1	0.541	4990	294	249.5	10.52	0	0	12.13	0.715	0.606	0.104	52	85
2	0.380	5594	330	279.7	11.79	0	0	13.60	0.802	0.680	0.117	52	76
3	0.293	5984	353	299.2	12.62	0	0	14.55	0.858	0.727	0.125	52	71
4	0.679	4420	260	221.0	9.32	0	0	10.75	0.634	0.537	0.092	67	124
5	0.444	5373	317	268.6	11.33	0	0	13.06	0.770	0.653	0.112	67	102
6	0.330	5871	346	293.5	12.38	0	0	14.28	0.842	0.714	0.123	67	93
7	0.664	4477	264.1	223.8	9.45	0	0	10.89	0.642	0.544	0.093	25	45

Table 8.8 (D) The estimated potential reductions and payback periods of the proposed roofs in Majd mosque

Roof Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	2.832	47420											
0	1.096	6271	370	313.5	13.22	0.000	0.0	20.907	1.233	1.045	0.180	40	38
1	0.892	7110	419	355.5	14.99	0.112	3.8	23.702	1.398	1.185	0.204	70	59
2	0.681	7881	464	394.0	16.62	0.112	3.8	26.272	1.550	1.313	0.226	97	73
3	0.444	8707	513	435.3	18.36	0.168	5.7	29.024	1.712	1.451	0.250	97	66
4	0.330	9165	540	458.2	19.32	0.168	5.7	30.552	1.802	1.527	0.263	97	63
5	0.794	7462	440	373.1	15.73	0.112	3.8	24.874	1.467	1.243	0.214	76	61
6	0.490	8578	506	428.9	18.09	0.168	5.7	28.597	1.687	1.429	0.246	76	53
7	0.354	9074	535	453.7	19.13	0.168	5.7	30.250	1.784	1.512	0.260	76	50

Table 8.8 (E) The estimated percentages of air conditioning energy reductions of the proposed measures in Majd mosque

		R0	R1	R2	R3	R4	R5	R6	R7
		13.226	14.995	16.62	18.362	19.328	15.736	18.091	19.137
W0	7.438	20.664	22.433	24.058	25.8	26.766	23.174	25.529	26.575
W1	10.523	23.749	25.518	27.143	28.885	29.851	26.259	28.614	29.66
W2	11.798	25.024	26.793	28.418	30.16	31.126	27.534	29.889	30.935
W3	12.620	25.846	27.615	29.24	30.982	31.948	28.356	30.711	31.757
W4	9.323	22.549	24.318	25.943	27.685	28.651	25.059	27.414	28.46
W5	11.331	24.557	26.326	27.951	29.693	30.659	27.067	29.422	30.468
W6	12.382	25.608	27.377	29.002	30.744	31.71	28.118	30.473	31.519
W7	9.450	22.676	24.445	26.07	27.812	28.778	25.186	27.541	28.587

Table 8.8 (F) The estimated reductions and the payback periods under various combinations of modified roof and walls (namely giving higher saving percentages in air conditioning energy).

Roof Type	Wall Type	U- value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
4	3	0.623	15150	893	757.50	31.94	0.784	26.75	45.10	2.660	2.255	0.388	149	66
4	6	0.660	15037	887	751.85	31.71	0.784	26.75	44.83	2.644	2.241	0.386	164	77
7	3	647.000	15059	888	752.95	31.75	0.784	26.75	44.80	2.643	2.240	0.386	128	57
7	6	0.684	14946	881	747.30	31.52	0.784	26.75	44.53	2.627	2.226	0.383	143	64
4	2	0.710	14760	870	738.00	31.12	0.784	26.75	44.15	2.604	2.207	0.380	149	67
7	2	0.734	14669	865	733.45	30.93	0.784	26.75	43.85	2.587	2.192	0.378	128	58
4	5	0.774	14538	857	726.90	30.66	0.784	26.75	43.61	2.572	2.180	0.375	164	75
3	3	0.737	14692	866	734.60	30.98	0.784	26.75	43.57	2.570	2.178	0.375	149	68
7	5	0.798	14448	852	722.40	30.46	0.728	24.84	43.31	2.555	2.165	0.373	143	66
3	6	0.774	14578	860	728.90	30.74	0.784	26.75	43.30	2.554	2.165	0.373	164	75
6	3	0.783	14563	859	728.15	30.71	0.784	26.75	43.14	2.545	2.157	0.371	128	59
4	1	0.871	14155	835	707.75	29.85	0.728	24.84	42.68	2.518	2.134	0.367	149	69

8.2.1.3 Case study I-B: Al-Forkan Mosque

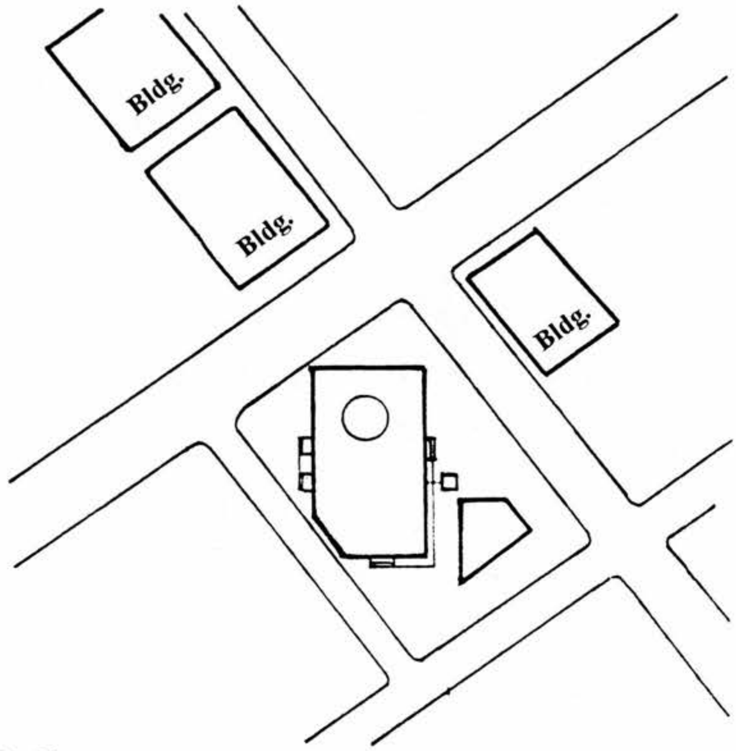
Al-Forkan mosque is the second selected mosque to represent the first category of the surveyed mosques. The mosque is located in Al-Bawadi district; one of the new Jeddah's suburb. It is a two storey mosque with a total height of 6 metres. The plot on which the mosque is situated is bounded by four local street isolating the mosque from other neighbouring buildings. The mosque covers only 29% of the plot while the mosque's services utilise 7%. 65% of the plot is left as open spaces.

8.2.1.3.1 Mosque conditions

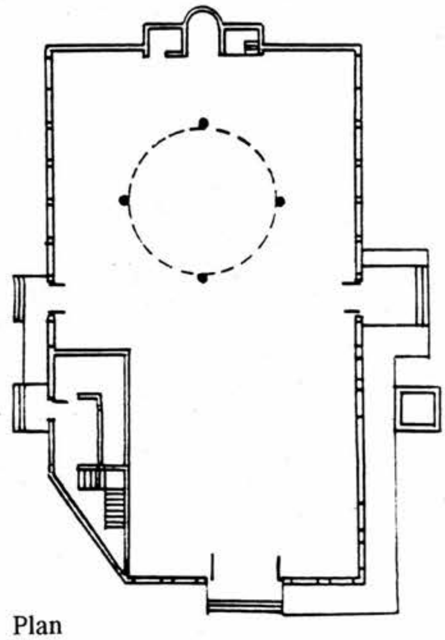
The ground floor level is used as male prayer hall with a height of two floors. A mezzanine floor level, part of the second floor, is used as female prayer hall approached by a stair case located in the north west corner. The surface around the mosque is paved which increases the solar radiation intensity around the mosque (see figures 8.3 A and B).

The mosque accommodates approximately 566 worshippers (416 male and 150 female) of various ages. The mosque is usually full with the worshippers in the Friday prayer and about a third occupied during Duhur and Asr prayers. In Magrib and Isha'a prayers the attendance covers two third of the mosque and about a fourth in Fajr prayer.

The plot gross area is approximately 1504 square metres and the net built area is 448 square metres for the mosque and 100 square metres for the services quarter which is completely isolated from the mosque building. A summary of the mosque's details is listed in Table 8.9.

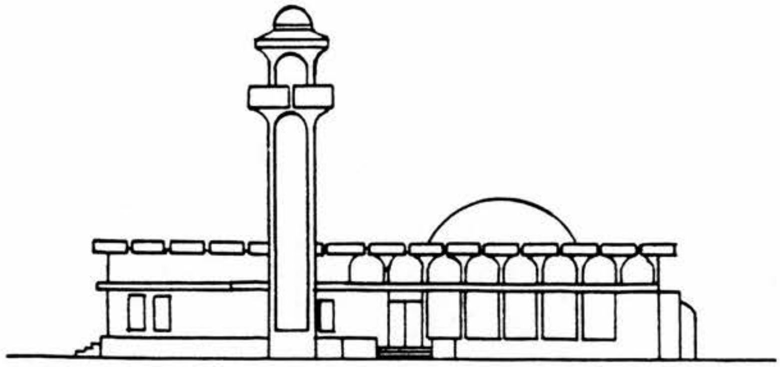


Site Plan

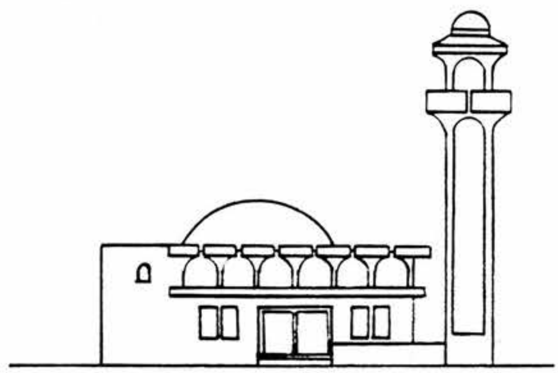


Plan

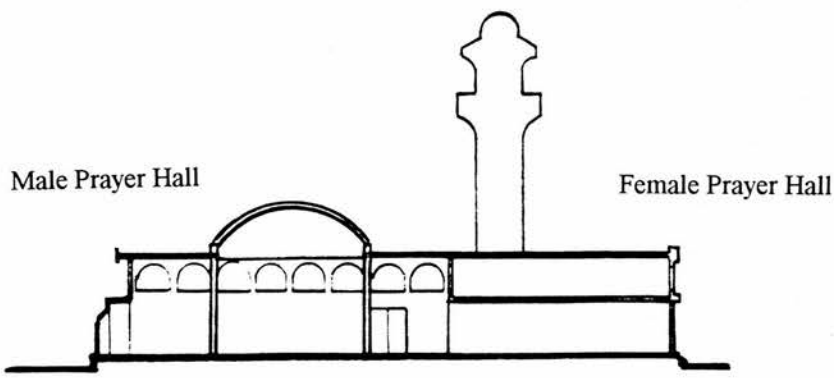
Figure 8.3 (A) The urban configuration of Al-Forkan mosque, showing the mosque in relation to its neighbours (upper) and the ground floor plan of the mosque (lower).



South Elevation



West Elevation



Section

Figure 8.3 (B) South and west elevations and section of Al-Forkan mosque.

Table 8.9 Some details of Al-Forkan mosque

ITEMS	Al-Forkan
Dimensions	mosque
Plot size	1504 sq. m
Mosque area	448 sq. m
Mosque volume	1947 cub. m
Number of worshippers	566
Mosque services area	100 sq. m
U- Value (W/m^2 k)	
. External walls: 210 mm thick concrete block with 50 mm sand cement mortar and 20mm marble tiles	1.002
. Glazing: Single glazed windows	5.6
. Roof: Tiled reinforced concrete flat roof with plastered ceiling	2.922
. Floor: Reinforced concrete floor in contact with the earth, tiled and carpeted	1.13
Internal temperature	23°C
External temperature	37.5°C
Areas	
. Exposed prayer hall's walls to the outdoor environment	279 sq. m
. Glazing	26 sq. m
. Flat roof	336 sq. m

8.2.1.3.2 Energy, active and passive cooling used

The most common energy used in this mosque as in all the mosques in the region is electricity. Electricity is used for cooling systems and appliances. The average monthly air conditioning energy consumption and the number of air conditioners involved are shown in Table 8.10. The average annual energy consumption is 84159 Kwh, where 86% is used for the cooling systems and 14% is consumed by other appliances. The average annual cooling energy consumption for one cubic metre is about 37.32 Kwh and the related amount of CO_2 is 2.2 Kg. The appliances used in this mosque are sound amplifier system, air conditioners, 14 ceiling fans, 1 water cooler, and 80 lights.

The cooling systems used in this mosque are air conditioners and fans. Five floor and wall types split unit air conditioners are used. The cooling systems are put on half an hour prior to the time for prayer's calling and put off twenty minutes after the prayer has finished. No frequent service is carried out to the air conditioners but they are normally reinjected with refrigerants every 5 to 6 years. The cooling systems are usually used during daily and Friday prayers, 24 special lectures delivered annually each lasts for 30 minutes. The outdoor units of these air conditioners are placed on the ground level around the mosque changing the micro climate around the mosque and increasing the air temperature. These air conditioners are not used for most of January. The managers of this mosque are aware of the high energy cost but not the environmental cost of using the air conditioning system. They use natural ventilation during the prayer times for the whole month of January and two times a month for 15 minutes before Duhur prayer when the mosque is not in use.

8.2.1.3.3 The proposed strategy and measures' performances

The results of the proposed strategy and measures potential savings are listed in Tables 8.11 and 8.12 (A, B, C, D, E and F) respectively.

Table 8.10 Average monthly air conditioning energy consumption (Kwh) and the number of air conditioners used in Forkan mosque.

Month	Air conditioning energy (Kwh)	Numbers of A/C units	Numbers of A/C units
January	0	0	0
February	4348	4	2
March	7579	5	4
April	7129	5	4
May	8929	5	5
June	11561	5	5
July	9910	5	5
August	7978	5	4
September	6378	5	4
October	4917	4	2
November	1999	4	0
December	1944	4	0

Table 8.11 The estimated potential reductions of the proposed passive cooling strategy in Forkan mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Thermal mass and air movement	61158.27	3608.33	3057.91	84.15	2.907	84.24	31.41	1.853	1.57	.27

Table 8.12 (A) The estimated potential reductions of the proposed measure of night ventilation in Forkan mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Night Ventilation	841	49.619	42.05	1.10	0	0	0.432	0.025	0.021	0.003

Table 8.12 (B) The estimated potential reductions and payback periods of the proposed measure of complete shading existing windows in Forkan mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost 1 m^2 (SRi)	Pay back period (years)
Shading Windows	4066	239.9	203.32	5.59	0	0	155.489	9.172	7.768	1.331	65	8.36

Table 8.12 (C) The estimated potential reductions and payback periods of the proposed walls in Forkan mosque

Wall Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	1.770	72672											
0	0.926	2401	141.6	120.0	3.30	0	0	8.609	0.507	0.430	0.074	25	58
1	0.541	3397	200.4	169.8	4.67	0	0	12.178	0.718	0.608	0.104	52	85
2	0.380	3809	224.7	190.4	5.24	0	0	13.654	0.805	0.682	0.117	52	76
3	0.293	4075	240.4	203.7	5.60	0	0	14.606	0.861	0.730	0.125	52	71
4	0.679	3010	177.5	150.5	4.14	0	0	10.790	0.636	0.539	0.093	67	124
5	0.444	3658	215.8	182.9	5.03	0	0	13.114	0.773	0.655	0.113	67	102
6	0.330	3998	235.8	199.9	5.50	0	0	14.331	0.845	0.716	0.123	67	93
7	0.664	3048	179.8	152.4	4.19	0	0	10.928	0.644	0.546	0.094	25	45

Table 8.12 (D) The estimated potential reductions and payback periods of the proposed roofs in Forkan mosque

Roof Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	2.832	72672											
0	1.096	7027	414.5	351.3	9.66	0.000	0.0	20.913	1.2337	1.045	0.180	40	38
1	0.892	7966	469.9	398.3	10.96	0.056	1.6	23.710	1.3980	1.185	0.204	70	59
2	0.681	8830	520.9	441.5	12.15	0.056	1.6	26.280	1.5500	1.314	0.226	97	73
3	0.444	9755	575.5	487.7	13.42	0.112	3.2	29.034	1.7130	1.451	0.250	97	66
4	0.330	10268	605.8	513.4	14.13	0.112	3.2	30.562	1.8030	1.528	0.263	97	63
5	0.794	8360	493.2	418.0	11.50	0.056	1.6	24.882	1.4680	1.244	0.214	76	61
6	0.490	9611	567.0	480.5	13.22	0.112	3.2	28.606	1.6870	1.430	0.246	76	53
7	0.354	10167	599.8	508.3	13.99	0.112	3.2	30.260	1.7850	1.513	0.260	76	50

Table 8.12 (E) The estimated percentages of air conditioning energy reductions of the proposed measures in Forkan mosque

		R0	R1	R2	R3	R4	R5	R6	R7
		9.66	10.96	12.15	13.42	14.13	11.5	13.22	13.99
W0	3.30	12.96	14.26	15.45	16.72	17.43	14.8	16.52	17.29
W1	4.67	14.33	15.63	16.82	18.09	18.8	16.17	17.89	18.66
W2	5.24	14.9	16.2	17.39	18.66	19.37	16.74	18.46	19.23
W3	5.60	15.26	16.56	17.75	19.02	19.73	17.1	18.82	19.59
W4	4.14	13.8	15.1	16.29	17.56	18.27	15.64	17.36	18.13
W5	5.03	14.69	15.99	17.18	18.45	19.16	16.53	18.25	19.02
W6	5.50	15.16	16.46	17.65	18.92	19.63	17	18.72	19.49
W7	4.19	13.85	15.15	16.34	17.61	18.32	16.69	17.41	18.18

Table 8.12 (F) The estimated reductions and the payback periods under various combinations of modified roof and walls (namely giving higher saving percentages in air conditioning energy).

Roof Type	Wall Type	U- value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
4	3	0.623	14338	845	716.90	19.73	0.280	8.11	45.168	2.664	2.258	0.389	149	65
4	6	0.660	14265	841	713.25	19.63	0.280	8.11	44.893	2.648	2.244	0.387	164	73
7	3	0.647	14236	839	711.80	19.59	0.280	8.11	44.866	2.647	2.243	0.386	128	57
7	6	0.684	14163	835	708.15	19.49	0.280	8.11	44.591	2.630	2.229	0.384	143	64
4	2	0.710	14076	830	703.80	19.37	0.224	6.40	44.216	2.608	2.210	0.381	149	67
7	2	0.734	13974	824	698.70	19.23	0.224	6.40	43.914	2.590	2.195	0.378	128	58
4	5	0.774	13924	821	696.20	19.16	0.224	6.40	43.676	2.576	2.183	0.376	164	75
3	3	0.737	13822	815	691.10	19.02	0.224	6.40	43.640	2.574	2.182	0.376	149	68
7	5	0.798	13822	815	691.10	19.02	0.224	6.40	43.374	2.559	2.168	0.373	143	65
3	6	0.774	13749	811	687.45	18.92	0.224	6.40	43.365	2.558	2.168	0.373	164	75
6	3	0.783	13676	806	683.80	18.82	0.224	6.40	43.212	2.549	2.160	0.372	128	59
4	1	0.871	13662	806	683.10	18.80	0.224	6.40	42.740	2.521	2.137	0.368	149	69

8.2.2 Large District Mosques

8.2.2.1 Case study II-A: Al-Rida Mosque

Al-Rida mosque is the first mosque to represent the second category (Large district mosque) of the surveyed mosques. The mosque is located in one of the residential district to the north of the city called Al-Naeem. It is a two-storey mosque with a total height of 7 metres. The plot where the mosque stands is bounded by a major road from the western side and by local street from the north. Another local street runs to the south carrying a low mass of traffic. A separate service quarter is located in the south east and about 10 metres away from the mosque. It accommodates the Imam, Muaddin, and the ablution facilities.

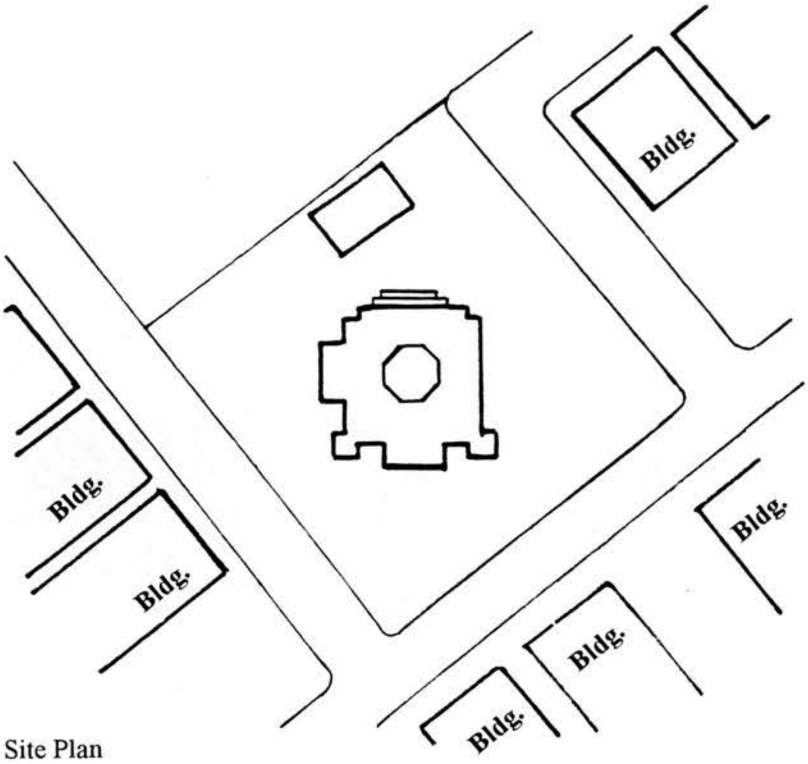
8.2.2.1.1 Mosque conditions

The mosque consists of two prayer halls; the ground floor is for men and the mezzanine floor is for women. The mezzanine floor is approached by a separate stair case located in the south west corner (see figures 8.4 A and B).

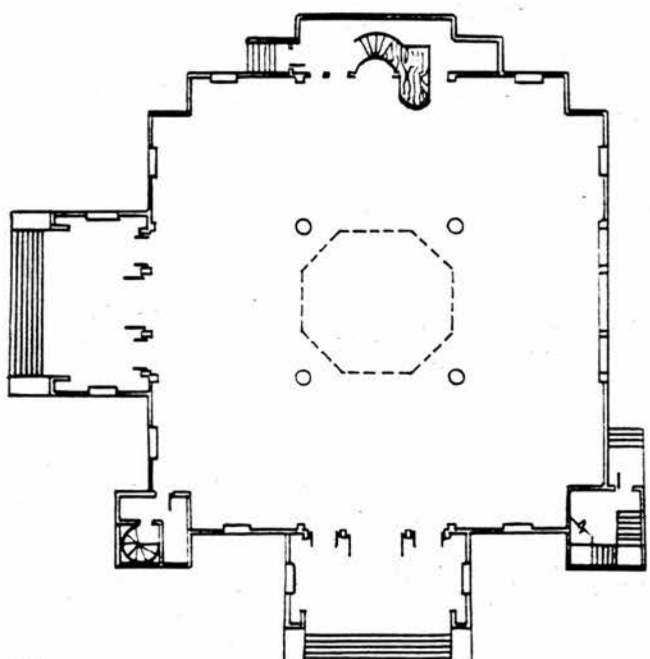
The mosque accommodates 741 persons of different ages and sexes. Usually, on daily prayers the attendance is about a third. The mosque is always full on the Friday prayer. The managers of this mosque are well educated adults. The net built area of the mosque is about 272 square metres and the service quarter covers 50 square metres. A summary of the mosque's details is listed in Table 8.13.

8.2.2.1.2 Energy, active and passive cooling systems used

The energy used in this mosque is electricity. Electricity is used for the

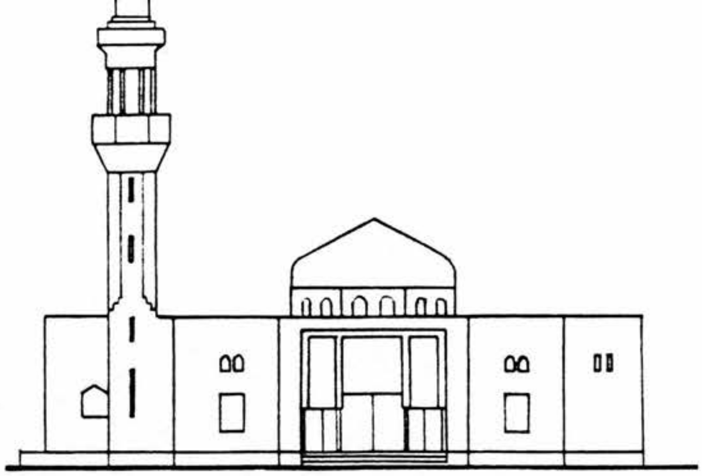


Site Plan

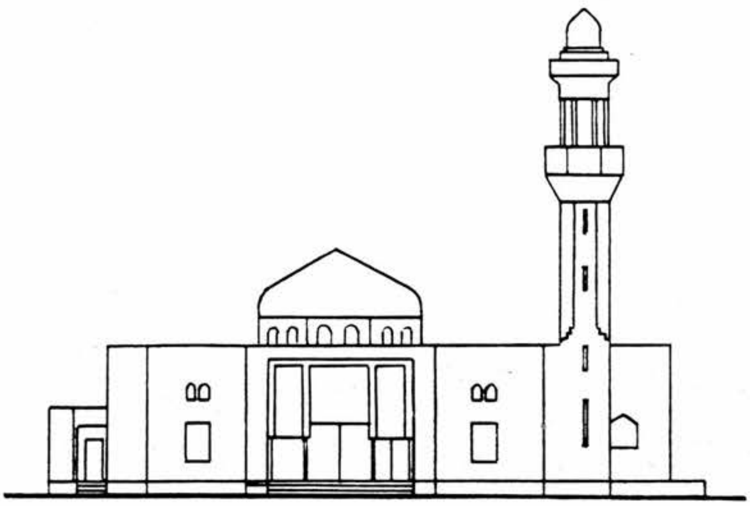


Plan

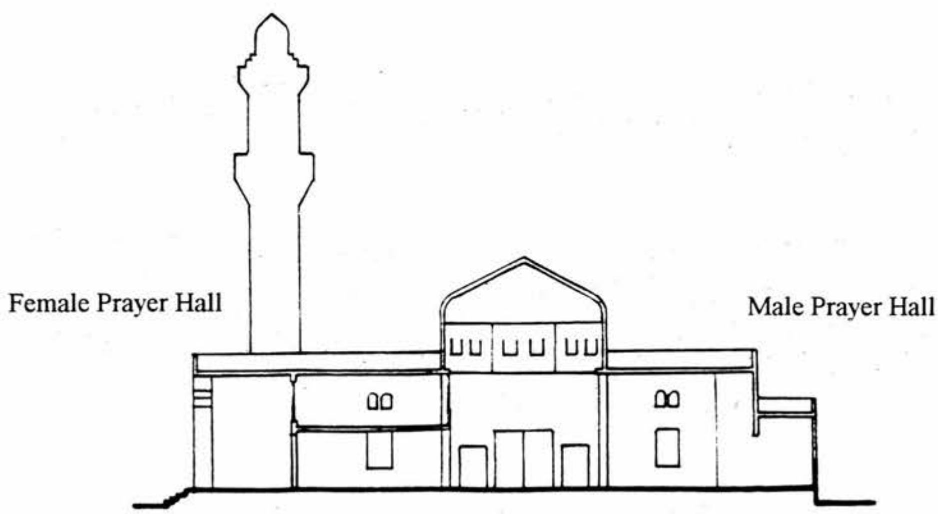
Figure 8.4 (A) The urban configuration of Al-Rida mosque, showing the mosque in relation to its neighbours (upper) and the ground floor plan of the mosque (lower).



North Elevation



West Elevation



Section

Figure 8.4 (B) West and north elevations and section of Al-Rida mosque.

Table 8.13 Some details of Al-Rida mosque details

ITEMS	**Al-Rida**
Dimensions	**mosque**
Plot size	4620 sq. m
Mosque area	756 sq. m
Mosque volume	3859 cub. m
Number of worshippers	741 person
Mosque services area	322 sq. m
U- Value (W/m^2 k)	
. External walls: 210 mm thick concrete block with 50 mm sand cement mortar and 20mm marble tiles	1.002
. Glazing: Single glazed windows	5.6
. Roof: Tiled reinforced concrete flat roof with plastered ceiling	2.922
. Floor: Reinforced concrete floor in contact with the earth, tiled and carpeted	1.13
Internal temperature	25°C
External temperature	36°C
Areas	
. Exposed prayer hall's walls to the outdoor environment	644 sq. m
. Glazing	45.8 sq. m
. Flat roof	494 sq. m

appliances and the air conditioning system. The average monthly air conditioning energy consumption and the number of air conditioners involved are shown in Table 8.14. The annual average energy consumption of this mosque is 59323 Kwh. 46123

Table 8.14 Average monthly air conditioning energy consumption (Kwh) and the number of air conditioners used in Rida mosque.

Month	Air conditioning energy (Kwh)	Numbers of A/C units
January	0	0
February	2209	4
March	2793	4
April	3478	5
May	4193	5
June	7373	6
July	5981	6
August	5757	6
September	4974	5
October	4599	5
November	2621	4
December	2145	4

Kwh is consumed by the cooling systems and 13200 Kwh is used by the other appliances. The annual average cooling energy is nearly 11.95 Kwh for each cubic metre of the prayer hall responsible of emitting 0.705 Kg of CO_2. The mosque accommodates the following appliances; 3 water coolers, 1 sound amplifier, air conditioners, 16 ceiling fans and 16 wall fans, and 100 lights.

The cooling systems used in this mosque are split type air conditioners and fans. The systems are normally switched on 15 to 20 minutes prior to the call of the prayer and switched off 15 minutes after the prayer has finished. The outdoor units of these air conditioners emit heat in its operation. Unfortunately, they are placed at ground level around the mosque. This heat goes back into the mosque by two means; either by infiltration through cracks, windows and doors or by conduction through the building envelopes. With the presence of these units around the mosque a very hot environment is created. No periodic maintenance is carried out to these air conditioners and the service may take place only if the system is broken or when the system is out of refrigerant gas. The thermostat of these units are always kept on one level (25°C). The cooling systems are used during the daily and Friday prayers, the teaching of the Holy Quran that lasts for 30 to 45 minutes on a daily basis and the monthly special lecture which lasts for 30 minutes. Finally, these air conditioners are not used in January. The managers of this mosque uses mesh aluminium-type sun breakers on the windows. They use natural ventilation during the prayer times for the whole month of January. The mosque is also ventilated 10 times a month for 15 to 30 minutes when the mosque is not used.

8.2.2.1.3 The proposed strategy and measures' performances

The results of the proposed passive cooling strategy and the measures potential savings are listed in Tables 8.15 and 8.16 (A, B, C, D, E and F) respectively. The calculation processes are shown in Appendix 1.A and 1.B.

Table 8.15 **The estimated potential reductions of the proposed passive cooling strategy in Rida mosque**

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Thermal mass and air movement	38466.87	2269.54	1923.34	83.4	2.70	86.28	9.968	0.588	0.498	0.085

Table 8.16 (A) **The estimated potential reductions of the proposed measure of night ventilation in Rida mosque**

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Night Ventilation	1685	99.415	84.25	3.6	0	0	0.436	0.025	0.021	0.003

Table 8.16 (B) **The estimatedpotential reductions and payback periods of the proposed measure of complete shading existing windows in Rida mosque**

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost 1 m^2 (SRi)	Pay back period (years)
Shading Windows	7822	461.54	391.14	16.96	0.232	7.4	170.98	10.08	8.533	1.458	65	7.61

Table 8.16 (C) The estimated potential reductions and payback periods of the proposed walls in Rida mosque

Wall Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	1.770	46123											
0	0.926	5577	329.0	278.8	12.09	0.000	0.00	8.661	0.510	0.433	0.074	25	57
1	0.541	7889	465.4	394.4	17.10	0.116	3.70	12.251	0.722	0.612	0.105	52	84
2	0.380	8845	521.8	442.2	19.17	0.232	7.41	13.735	0.810	0.686	0.118	52	75
3	0.293	9462	558.2	473.1	20.51	0.464	14.82	14.693	0.866	0.734	0.126	52	70
4	0.679	6884	406.1	344.2	14.92	0.000	0.00	10.690	0.630	0.534	0.092	67	125
5	0.444	8495	501.2	424.7	18.42	0.232	7.41	13.192	0.778	0.659	0.113	67	101
6	0.330	9284	547.7	464.2	20.12	0.406	12.97	14.416	0.850	0.720	0.124	67	92
7	0.664	7079	417.6	353	15.34	0.000	0.00	10.993	0.648	0.549	0.094	25	45

Table 8.16 (D) The estimated potential reductions and payback periods of the proposed roofs in Rida mosque

Roof Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	2.832	46123											
0	1.096	10333	609.6	516.6	22.40	0.464	14.82	20.917	1.234	1.045	0.180	40	38
1	0.892	11714	691.1	585.7	25.39	0.638	20.38	23.713	1.399	1.185	0.204	70	59
2	0.681	12984	766.0	649.2	28.15	0.638	20.38	26.284	1.550	1.314	0.226	97	73
3	0.444	14344	846.2	717.2	31.10	0.696	22.23	29.038	1.713	1.451	0.250	97	66
4	0.330	15099	890.8	754.9	32.73	0.696	22.23	30.566	1.803	1.528	0.263	97	63
5	0.794	12293	725.2	614.6	26.65	0.638	20.23	24.886	1.468	1.244	0.214	76	61
6	0.490	14133	833.8	706.6	30.64	0.696	22.23	28.610	1.687	1.430	0.246	76	53
7	0.354	14950	882.0	747.5	32.41	0.696	22.23	30.264	1.785	1.513	0.260	76	50

Table 8.16 (E) The estimated percentages of air conditioning energy reductions of the proposed measures in Rida mosque

		R0	R1	R2	R3	R4	R5	R6	R7
		22.4	25.39	28.15	31.1	32.73	26.65	30.64	32.41
W0	12.09	34.49	37.48	40.24	43.19	44.82	38.74	42.73	44.5
W1	17.10	39.5	42.49	45.25	48.2	49.83	43.75	47.74	49.51
W2	19.17	41.57	44.56	47.32	50.27	51.9	45.82	49.81	51.58
W3	20.51	42.91	45.9	48.66	51.61	53.24	47.16	51.15	52.92
W4	14.92	37.32	40.31	43.07	46.02	47.65	41.57	45.56	47.33
W5	18.42	40.82	43.81	46.57	49.52	51.15	45.07	49.06	50.83
W6	20.12	42.52	45.51	48.27	51.22	52.85	46.77	50.76	52.53
W7	15.34	37.74	40.73	43.49	46.44	48.07	41.99	45.98	47.75

Table 8.16 (F) The estimated reductions and the payback periods under various combinations of modified roof and walls (namely giving higher saving percentages in air conditioning energy).

Roof Type	Wall Type	U- value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
4	3	0.623	24555	1448	1227.7	53.20	1.392	44.47	45.260	2.670	2.2630	0.390	149	65
7	3	0.647	24408	1440	1220.4	52.90	1.392	44.47	44.958	2.652	2.2479	0.387	128	56
4	6	0.660	24376	1438	1218.8	52.80	1.392	44.47	44.983	2.653	2.2490	0.387	164	72
7	6	0.684	24228	1429	1211.4	52.50	1.334	42.61	44.680	2.636	2.2340	0.385	143	64
4	2	0.710	23937	1412	1196.8	51.90	1.334	42.61	44.301	2.613	2.2150	0.381	149	67
3	3	0.737	23804	1404	1190.2	51.60	1.334	42.61	43.731	2.580	2.1860	0.376	149	68
7	2	0.734	23790	1403	1189.5	51.50	1.334	42.61	43.999	2.595	2.1990	0.379	128	58
3	6	0.774	23624	1393	1181.2	51.20	1.334	42.61	43.454	2.563	2.1720	0.374	164	75
4	5	0.774	23591	1391	1179.5	51.15	1.334	42.61	43.758	2.581	2.1870	0.377	164	74
6	3	0.783	23591	1391	1179.5	51.15	1.334	42.61	43.303	2.554	2.1650	0.373	128	59
7	5	0.798	23444	1383	1172.2	50.83	1.334	42.61	43.456	2.563	2.1720	0.374	143	65
6	6	0.820	23412	1381	1170.6	50.76	1.334	42.61	43.026	2.538	2.1510	0.370	143	66

8.2.2.2 Case study II-B: Ibn Abbas Mosque

Ibn Abbas mosque is selected to represent large district mosques with moderate air conditioning energy consumption. The mosque is located in Al-Naeem district; one of the new Jeddah's suburb. It is a two storey mosque with a total height of 6 metres. The plot on which the mosque is situated is bounded by four local street isolating the mosque from other neighbouring buildings. The mosque covers only 16% of the plot while the mosque's services occupies 7.6%. The remaining 76.4% of the plot is left as open space.

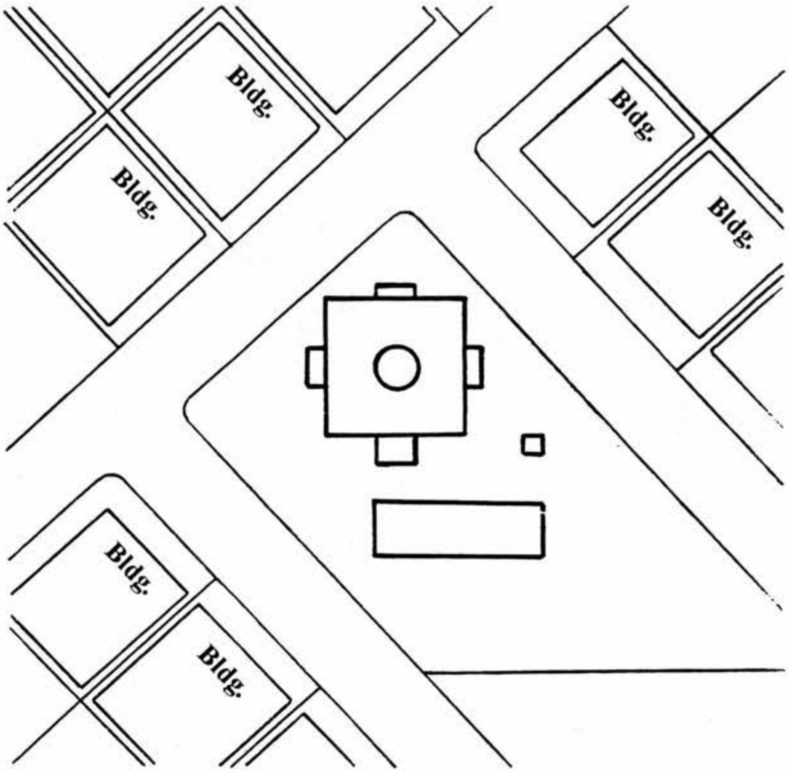
8.2.2.2.1 Mosque conditions

The ground floor level is used as male prayer hall with a height of two floors. A mezzanine floor level, part of the second floor, is used as female prayer hall approached by a stair case located in the west. The surface around the mosque is paved which increase the solar radiation intensity around the mosque (fig. 8.5 A & B).

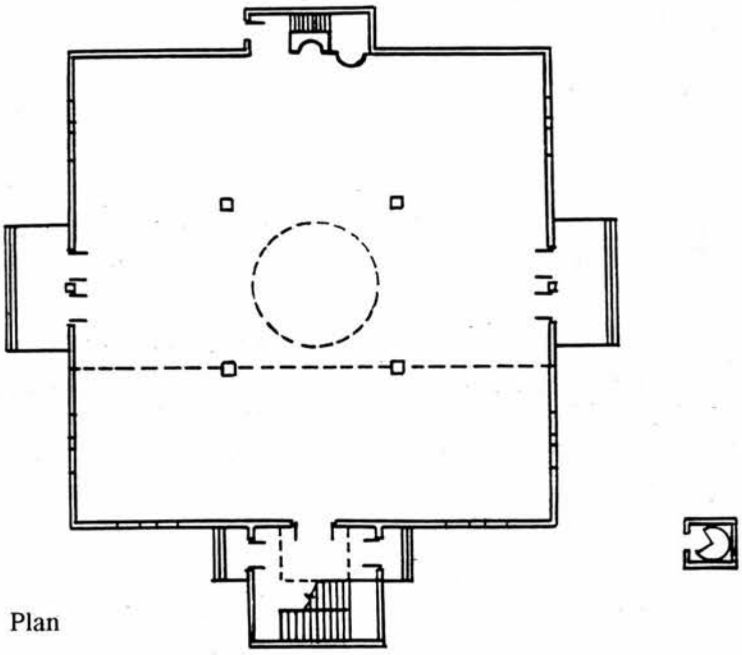
The mosque accommodates approximately 860 worshippers (646 male and 214 female) of various ages. The mosque is usually full with the worshippers in the Friday prayer and about a third occupied during Duhur and Asr prayers. In Magrib and Isha'a prayers the attendance covers two third of the mosque and about a fourth in Fajr prayer. The plot gross area is approximately 3933 square metres and the net built area is 625 square metres for the mosque and 300 square metres for ablution and residential quarters. A summary of the mosque's details is listed in Table 8.17.

8.2.2.2.2 Energy, active and passive cooling systems used

The most common energy used in this mosque as in all the mosques in the

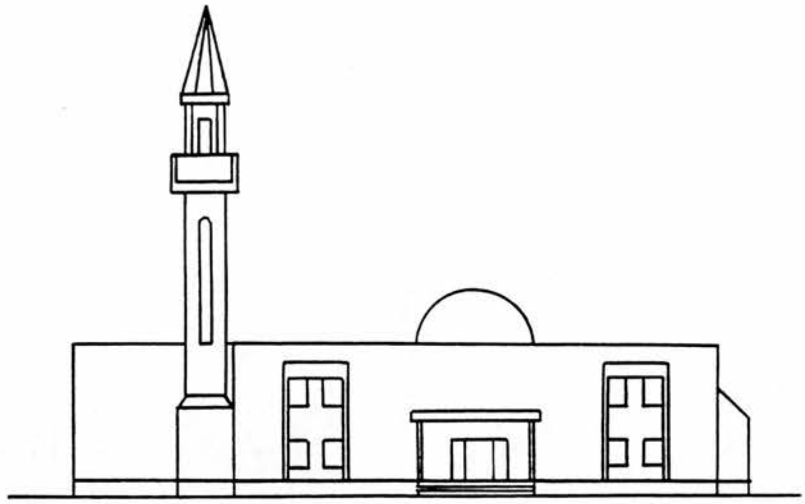


Site Plan

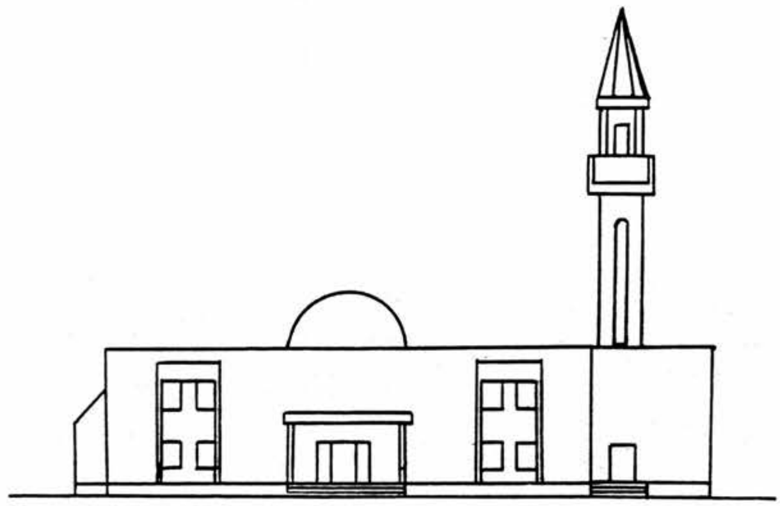


Plan

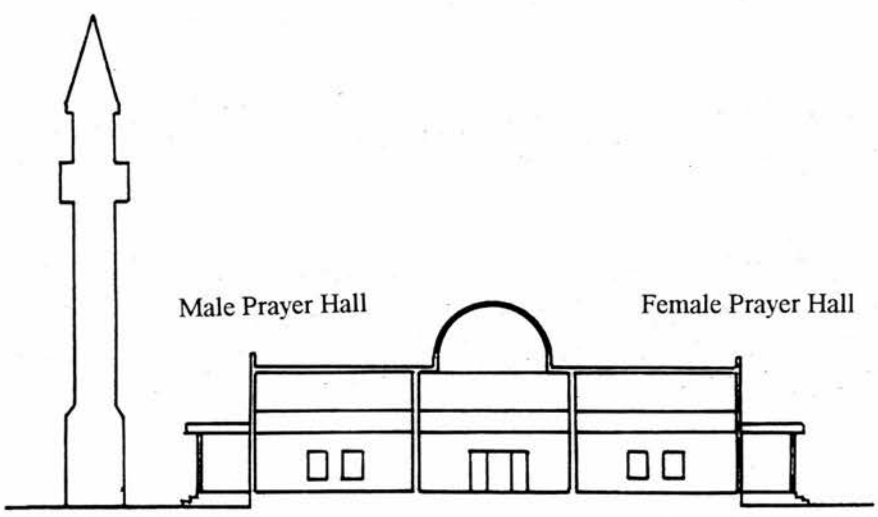
Figure 8.5 (A) The urban configuration of Ibn Abbas mosque, showing the mosque in relation to its neighbours (upper) and the ground floor plan of the mosque (lower).



South Elevation



North Elevation



Section

Figure 8.5 (B) South and west elevations and section of Ibn Abbas mosque.

Table 8.17 Some details of Ibn Abbas mosque

ITEMS	Ibn Abbas
Dimensions	mosque
Plot size	3933 sq. m
Mosque area	625 sq. m
Mosque volume	3768 cub. m
Number of worshippers	859 person
Mosque services area	300 sq. m
U- Value (W/m^2 k)	
. External walls: 210 mm thick concrete block with 50 mm sand cement mortar and 20mm marble tiles	1.002
. Glazing: Single glazed windows	5.6
. Roof: Tiled reinforced concrete flat roof with plastered ceiling	2.922
. Floor: Reinforced concrete floor in contact with the earth, tiled and carpeted	1.13
Internal temperature	24°C
External temperature	37.5°C
Areas	
. Exposed prayer hall's walls to the outdoor environment	558 sq. m
. Glazing	35.7 sq. m
. Flat roof	596 sq. m

region is electricity. Electricity is used for cooling systems and appliances. The average monthly air conditioning energy consumption and the number of air conditioners involved are shown in Table 8.18. The average annual energy consumption is 113187 Kwh, where 80.12% (90687 Kwh) is used for the cooling

Table 8.18 Average monthly air conditioning energy consumption (Kwh) and the number of air conditioners used in Inb Abbas mosque.

Month	Air conditioning energy (Kwh)	Numbers of A/C units
January	0	0
February	2361	4
March	4285	5
April	5211	5
May	8266	6
June	13684	8
July	15746	8
August	13670	8
September	11548	8
October	7837	6
November	5250	5
December	2829	4

systems and 19.87% (22500 Kwh) is consumed by other appliances. The average annual cooling energy consumption for one cubic metre is about 24.06 Kwh and the related amount of CO_2 is 1.42 Kg. The appliances used in this mosque are sound amplifier system, air conditioners, 10 ceiling fans, 2 water cooler, and 100 lights.

The cooling systems used in this mosque are air conditioners and fans. Eight floor types split units air conditioners are used. The split type air conditioning system is very efficient in reducing infiltration and reducing the exhausted heat from the system. The cooling systems are put on 20 minutes prior to the time for prayers' calling and put off twenty minutes after the prayer has finished. No frequent service is carried out to the air conditioners but they are always reinjected with refrigerants every 5. The cooling systems are usually used during daily, Friday prayers and one special lecture delivered monthly and lasts for 30 minutes. The outdoor units of these air conditioners are placed on the ground level and therefore increasing the air temperature around the mosque. These air conditioners are not used in January.

The managers of this mosque are aware of the high energy cost but not the environmental cost of using the air conditioning system. They are trying very hard to save energy. They use natural ventilation during the prayer times for the whole month of January and two times a month for 10 to 15 minutes before Duhur prayer when the mosque is not in use. Moreover, poor design shading devices are used.

8.2.2.2.3 The proposed strategy and the measures' performances

The results of the proposed passive cooling strategy and the measures potential savings are listed in Tables 8.19 and 8.20 (A, B, C, D, E and F) respectively.

Table 8.19 The estimated potential reductions of the proposed passive cooling strategy in Ibn Abbas mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Thermal mass and air movement	72961.93	4304.75	3648.09	80.45	2.830	82.82	19.363	1.142	0.968	0.166

Table 8.20 (A) The estimated potential reductions of the proposed measure of night ventilation in Ibn Abbas mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Night Ventilation	1646	97.114	82.30	1.81	0	0	0.436	0.025	0.021	0.003

Table 8.20 (B) The estimated potential reductions and payback periods of the proposed measure of complete shading existing windows in Ibn Abbas mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost 1 m^2 (SRi)	Pay back period (years)
Shading Windows	5652	333.51	282.64	6.23	0	0	158.11	9.31	7.895	1.276	65	8.23

Table 8.20 (C) The estimated potential reductions and payback periods of the proposed walls in Ibn Abbas mosque

Wall Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	1.770	90687											
0	0.926	4833	285	241.6	5.33	0	0	8.662	0.511	0.433	0.074	25	57
1	0.541	6837	403	341.8	7.54	0	0	12.253	0.722	0.612	0.105	52	84
2	0.380	7663	452	383.1	8.45	0	0	13.738	0.810	0.686	0.118	52	75
3	0.293	8198	483	409.9	9.04	0	0	14.696	0.867	0.734	0.126	52	70
4	0.679	6057	357	302.8	6.68	0	0	10.856	0.640	0.542	0.093	67	123
5	0.444	7363	434	368.1	8.12	0	0	13.195	0.778	0.659	0.113	67	101
6	0.330	8043	474	402.1	8.87	0	0	14.419	0.850	0.720	0.124	67	92
7	0.664	6136	362	306.8	6.76	0	0	10.995	0.648	0.549	0.094	25	45

Table 8.20 (D) The estimated potential reductions and payback periods of the proposed roofs in Ibn Abbas mosque

Roof Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	2.832	90687											
0	1.096	12467	735	623.3	13.74	0.174	5.08	20.893	1.232	1.044	0.180	40	38
1	0.892	14134	833	706.7	15.58	0.232	6.77	23.686	1.397	1.184	0.204	70	59
2	0.681	15667	924	783.3	17.27	0.638	18.64	26.254	1.548	1.312	0.226	97	73
3	0.444	17308	1021	865.4	19.08	0.638	18.64	29.005	1.711	1.450	0.250	97	66
4	0.330	18219	1074	910.9	20.09	0.696	20.33	30.531	1.801	1.526	0.263	97	63
5	0.794	14833	875	741.6	16.35	0.348	10.16	24.858	1.466	1.242	0.214	76	61
6	0.490	17053	1006	852.6	18.80	0.638	18.64	28.578	1.686	1.428	0.246	76	53
7	0.354	18039	1064	901.9	19.89	0.638	18.64	30.230	1.783	1.511	0.260	76	50

Table 8.20 (E) The estimated percentages of air conditioning energy reductions of the proposed measures in Ibn Abbas mosque

		R0	R1	R2	R3	R4	R5	R6	R7
		13.748	15.586	17.276	19.086	20.09	16.357	18.805	19.892
W0	5.33	19.078	20.916	22.606	24.416	25.42	21.687	24.135	25.222
W1	7.54	21.288	23.126	24.816	26.626	27.63	23.897	26.345	27.432
W2	8.45	22.198	24.036	25.726	27.536	28.54	24.807	27.255	28.342
W3	9.04	22.788	24.626	26.316	28.126	29.13	25.397	27.845	28.932
W4	6.68	20.428	22.266	23.956	25.766	26.77	23.037	25.485	26.572
W5	8.12	21.868	23.706	25.396	27.206	28.21	24.477	26.925	28.012
W6	8.87	22.618	24.456	26.146	27.956	28.96	25.227	27.675	28.762
W7	6.76	20.50	22.34	24.03	25.84	26.85	23.11	25.56	26.65

Table 8.20 (F) The estimated reductions and the payback periods under various combinations of modified roof and walls (namely giving higher saving percentages in air conditioning energy).

Roof Type	Wall Type	U- value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
4	3	0.623	26421	1558	1321.0	29.13	0.870	25.42	45.228	2.668	2.261	0.389	149	65
4	6	0.660	26266	1549	1313.3	28.96	0.870	25.42	44.951	2.652	2.247	0.387	164	72
7	3	0.647	26242	1548	1312.1	28.93	0.870	25.42	44.927	2.650	2.246	0.387	128	56
7	6	0.684	26087	1539	1304.3	28.76	0.870	25.42	44.649	2.634	2.232	0.384	143	64
4	2	0.710	25886	1527	1294.3	28.54	0.812	23.72	44.269	2.611	2.213	0.381	149	67
7	2	0.734	25707	1516	1285.3	28.34	0.812	23.72	43.968	2.594	2.198	0.379	128	58
4	5	0.774	25583	1509	1279.1	28.21	0.812	23.72	43.726	2.579	2.186	0.376	164	75
3	3	0.737	25511	1505	1275.5	28.13	0.812	23.72	43.701	2.578	2.185	0.376	149	68
7	5	0.798	25404	1498	1270.2	28.01	0.812	23.72	43.425	2.562	2.171	0.374	143	65
3	6	0.774	25356	1496	1267.8	27.96	0.812	23.72	43.424	2.562	2.171	0.374	164	75
6	3	0.783	25256	1490	1262.8	27.85	0.812	23.72	43.274	2.553	2.163	0.373	128	59
4	1	0.871	25058	1478	1252.9	27.63	0.812	23.72	42.784	2.524	2.139	0.368	149	69

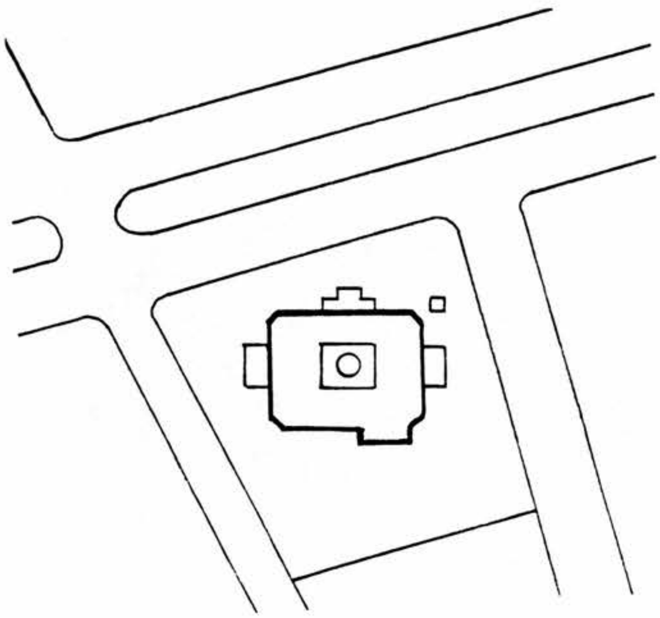
8.2.2.3 Case study II-B: Al-Taqwa Mosque

This mosque is the second mosque representing the second category of the surveyed mosques. It is located in a low density high class residential community. Moreover, the area is characterised by open areas for recreational purposes. The mosque is situated next to the intersection points between a major road of 30 metres wide to the east and a 15 metres wide street to the north. In addition, an un-asphalted street runs to the south and an empty vacant sandy plot is to the west. Mainly the east road carries a very large traffic volume which increase the heat environment around the mosque and pollutes the atmosphere. The mosque is totally separated from neighbouring buildings.

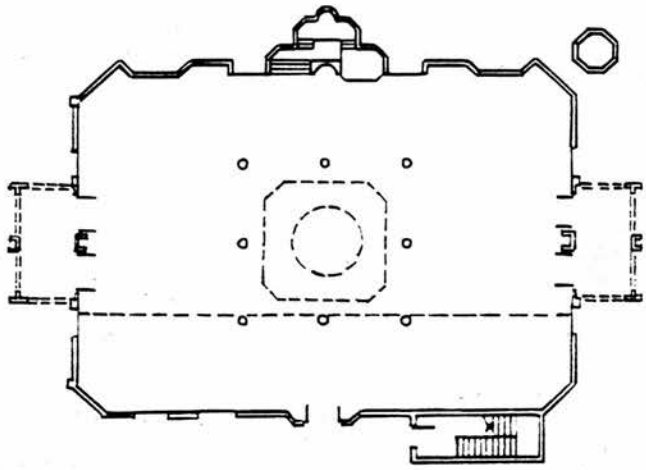
8.2.2.3.1 Mosque conditions

The mosque is a two-storey high building designed to accommodate men's prayer hall in the ground level and the women's prayer hall in a mezzanine floor. This mezzanine floor is designed at the back along the mosque and provided with private access from the west. The mosque dominates the north east part of the plot and is surrounded by paved open spaces. These paved areas increase the solar intensity around the mosque (figures 8.6 A and B).

The mosque can accommodate 611 worshippers of different ages. Only a third of the mosque is occupied during the daily prayers and fully occupied in the Friday prayer. The plot gross area is about 2412 square metres, the net of the built area is 513 square metres. A 30 square metres is designed for the service area located in the north west corner. A summary of the mosque's details is listed in Table 8.21.

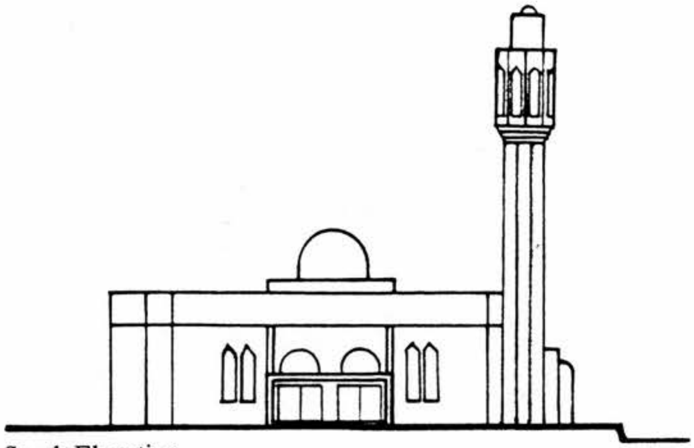


Site Plan

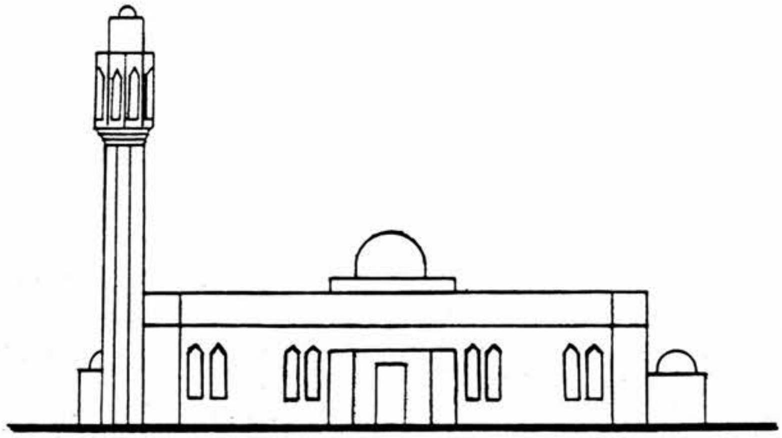


Plan

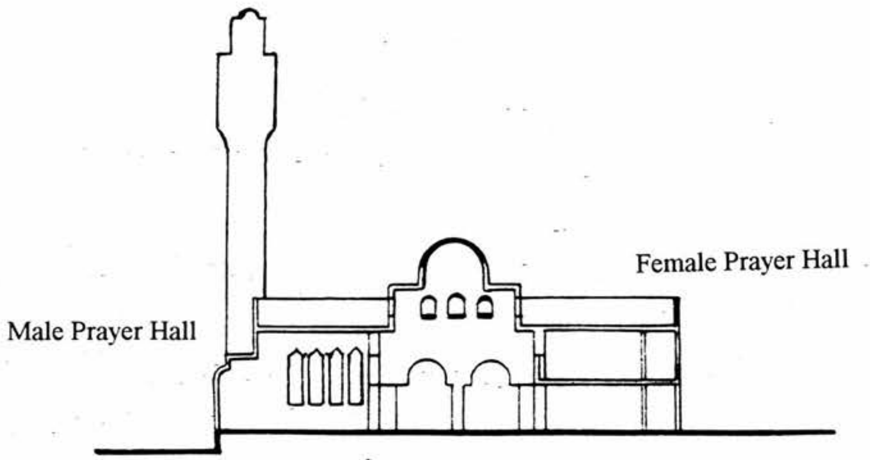
Figure 8.6 (A) The urban configuration of Al-Taqwa mosque, showing the mosque in relation to its neighbours (upper) and the ground floor plan of the mosque (lower).



South Elevation



East Elevation



Section

Figure 8.6 (B) South and east elevations and section of Al-Taqwa mosque.

Table 8.21 Some details of Al-Taqwa mosque

ITEMS	Al-Taqwa
Dimensions	**mosque**
Plot size	2412 sq. m
Mosque area	513 sq. m
Mosque volume	2407 cub. m
Number of worshippers	611 person
Mosque services area	30 sq. m
U- Value (W/m^2 k)	
. External walls: 210 mm thick concrete block with 50 mm sand cement mortar and 20mm marble tiles	1.002
. Glazing: Single glazed windows	5.6
. Roof: Tiled reinforced concrete flat roof with plastered ceiling	2.922
. Floor: Reinforced concrete floor in contact with the earth, tiled and carpeted	1.13
Internal temperature	23°C
External temperature	37.5°C
Areas	
. Exposed prayer hall's walls to the outdoor environment	348 sq. m
. Glazing	28 sq. m
. Flat roof	439 sq. m

8.2.2.3.2 Energy, active and passive cooling systems

The energy type used in this mosque is electricity. Electricity is used for cooling systems and other appliances and lights.

The managers of the mosque expressed their annoyance at the high energy consumption of the mosque. The average monthly air conditioning energy consumption and the number of air conditioners involved are shown in Table 8.22. Actually, the annual average amounts of energy used for cooling the mosque is approximately 105908 Kwh or 44 Kwh per cubic metre with the emission of 2.6 Kg of CO_2 gas. The different appliances available in the mosque are sound amplifier system, air conditioners, and lights.

The mosque is cooled mechanically by a central air conditioning system. The system consists of six units of 10 ton each. The thermostat is always left at 23°C. The system is reinjected with refrigerant every 5 years by a professional agent. The system are used for daily as well as Friday prayers and during the special lectures delivered twelve times annually for 30 minutes. The system is switched on 1 hour prior to the call to prayer and shut down 30 minutes after the prayer has finished. The system are switched off for the whole month of January.

The managers of Al-Taqwa mosque did many good efforts in saving energy. Shading devices were used in this mosque. They also use sun breakers on the windows. Furthermore, they use natural ventilation during the prayer times for most days of January. Finally, mosque is naturally ventilated two times a month for 5 to 10 minutes when the mosque is not used.

8.2.2.3.3 The proposed strategy and the measures' performances

The results of the proposed passive cooling strategy and the measures potential savings are listed in Tables 8.23 and 8.24 (A, B, C, D, E and F) respectively.

Table 8.22 Average monthly air conditioning energy consumption (Kwh) and the number of air conditioners used in Taqwa mosque.

Month	Air conditioning energy (Kwh)	Numbers of A/C units
January	0	0
February	3520	4
March	4523	5
April	6864	5
May	10736	6
June	17570	6
July	16491	6
August	14916	6
September	11246	6
October	9253	6
November	6576	5
December	4213	4

Table 8.23 The estimated potential reductions of the proposed passive cooling strategy in Taqwa mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Thermal mass and air movement	86410.33	5098.20	4320.51	81.59	3.590	87.11	35.899	2.118	1.794	0.309

Table 8.24 (A) The estimated potential reductions of the proposed measure of night ventilation in Taqwa mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Night Ventilation	1051	62.00	52.55	0.90	0	0	0.436	0.025	0.021	.003

Table 8.24 (B) The estimated potential reductions and payback periods of the proposed measure of complete shading existing windows in Taqwa mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost 1 m^2 (SRi)	Pay back period (years)
Shading Windows	5051	298.01	252.55	4.76	0	0	180.38	10.631	9.008	1.549	65	7.21

Table 8.24 (C) The estimated potential reductions and payback periods of the proposed walls in Taqwa mosque

Wall Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	1.770	105908											
0	0.926	3032	178.8	151.6	2.86	0	0	8.713	0.514	0.435	0.075	25	57
1	0.541	4288	252.9	214.4	4.04	0	0	12.323	0.727	0.616	0.106	52	84
2	0.380	4808	283.6	240.4	4.53	0	0	13.816	0.815	0.690	0.119	52	75
3	0.293	5143	303.4	257.1	4.85	0	0	14.780	0.872	0.739	0.127	52	70
4	0.679	3742	220.7	187.1	3.53	0	0	10.752	0.634	0.537	0.092	67	124
5	0.444	4618	272.4	230.9	4.36	0	0	13.270	0.782	0.663	0.114	67	100
6	0.330	5046	297.7	252.3	4.76	0	0	14.502	0.855	0.725	0.125	67	92
7	0.664	3848	227	192.4	3.63	0	0	11.057	0.652	0.552	0.095	25	45

Table 8.24 (D) The estimated potential reductions and payback periods of the proposed roofs in Taqwa mosque.

Roof Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	2.832	105908											
0	1.096	9182	541.7	459.1	8.66	0.00	0.00	20.916	1.234	1.045	0.180	40	38
1	0.892	10409	614.1	520.4	9.82	0.00	0.00	23.712	1.399	1.185	0.204	70	59
2	0.681	11538	680.7	576.9	10.89	0.07	1.60	26.283	1.550	1.314	0.226	97	73
3	0.444	12673	747.7	633.6	11.96	0.07	1.60	28.868	1.703	1.443	0.248	97	67
4	0.330	13418	791.6	670.9	12.66	0.21	5.08	30.565	1.803	1.528	0.263	97	63
5	0.794	10924	644.5	546.2	10.31	0.07	1.60	24.885	1.468	1.244	0.214	76	61
6	0.490	12559	740.9	627.9	11.85	0.07	1.60	28.609	1.687	1.430	0.246	76	53
7	0.354	13193	778.3	659.6	12.45	0.21	5.08	30.053	1.773	1.502	0.259	76	50

Table 8.24 (E) The estimated percentages of air conditioning energy reductions of the proposed measures in Taqwa mosque

		R0	R1	R2	R3	R4	R5	R6	R7
		8.66	9.82	10.89	11.96	12.66	10.31	11.85	12.45
W0	2.86	11.52	12.68	13.75	14.82	15.52	13.17	14.71	15.31
W1	4.04	12.7	13.86	14.93	16	16.7	14.35	15.89	16.49
W2	4.53	13.19	14.35	15.42	16.49	17.19	14.84	16.38	16.98
W3	4.85	13.51	14.67	15.74	16.81	17.51	15.16	16.7	17.3
W4	3.53	12.19	13.35	14.42	15.49	16.19	13.84	15.38	15.98
W5	4.36	13.02	14.18	15.25	16.32	17.02	14.67	16.21	16.81
W6	4.76	13.42	14.58	15.65	16.72	17.42	15.07	16.61	17.21
W7	3.63	12.29	13.45	14.52	15.59	16.29	13.94	15.48	16.08

Table 8.24 (F) The estimated reductions and the payback periods under various combinations of modified roof and walls (namely giving higher saving percentages in air conditioning energy).

Roof Type	Wall Type	U- value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
4	3	0.623	18544	1094	927.20	17.51	0.42	10.16	45.345	2.675	2.267	0.390	149	65
4	6	0.660	18449	1088	922.45	17.42	0.35	8.47	45.067	2.658	2.253	0.388	164	72
7	3	0.647	18322	1081	916.10	17.30	0.35	8.47	44.833	2.645	2.241	0.386	128	57
7	6	0.684	18226	1075	911.30	17.21	0.35	8.47	44.555	2.628	2.227	0.384	143	64
4	2	0.710	18205	1074	910.25	17.19	0.35	8.47	44.381	2.618	2.219	0.382	149	67
4	5	0.774	18025	1064	901.25	17.02	0.21	5.08	43.835	2.586	2.191	0.377	164	74
7	2	0.734	17983	1061	899.15	16.98	0.21	5.08	43.869	2.588	2.193	0.378	128	58
7	5	0.798	17803	1050	890.15	16.81	0.21	5.08	43.323	2.556	2.166	0.373	143	66
3	3	0.737	17803	1050	890.15	16.81	0.21	5.08	43.648	2.575	2.182	0.376	149	68
3	6	0.774	17707	1044	885.35	16.72	0.21	5.08	43.370	2.558	2.168	0.373	164	75
4	1	0.871	17686	1043	884.30	16.70	0.21	5.08	42.888	2.530	2.144	0.369	149	69
6	3	0.783	17686	1043	884.30	16.70	0.21	5.08	43.389	2.559	2.169	0.374	128	59

8.2.3 Central Mosques

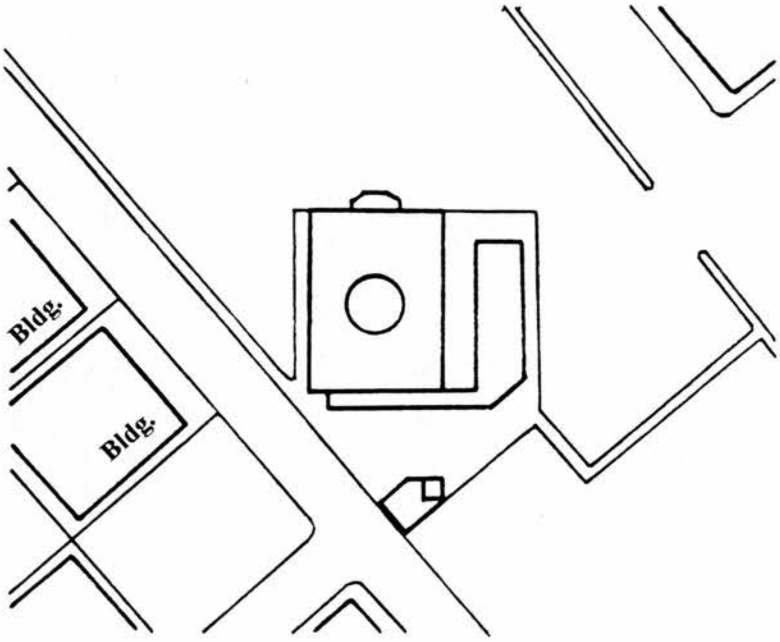
8.2.3.1 Case study III-A: Al-Amodi Mosque

Al-Amodi mosque is one of the two mosque which represent the third category of the surveyed mosques. The mosque and its services are built in the middle of an empty plot left for public services like mosque, schools, etc. Most of the mosque building is kept isolated from the Imam and Muaddin quarter and shops and far from the ablution area. The mosque is surrounded by a paved alley from the south and a local street of 15 metres wide from the north. Furthermore, a vacant land exists to the east and west. A paved open space is designed in front of the main entrance and is used sometimes to accommodate more worshippers.

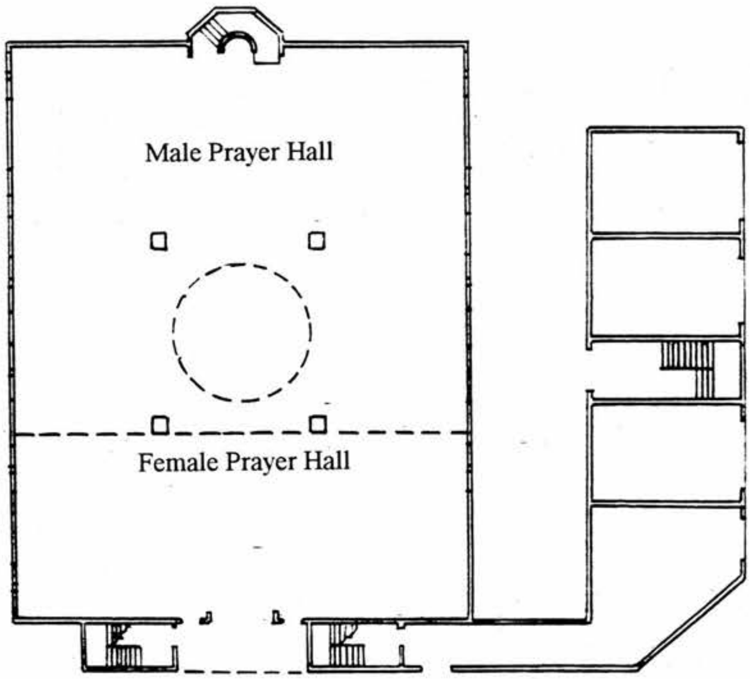
8.2.3.1.1 Mosque conditions

The mosque building consists of two floors. The ground level is used as a prayer hall for male and the upper mezzanine level is used as female prayer hall covering one third of the mosque (figures 8.7 A and B).

The mosque accommodate 972 persons of different ages (children, young, and old). The mosque is always full during Friday prayer and about a third occupied during the daily prayers. The plot gross area is approximately 4758 square metres and net built area is 1048 (758 square metres for the mosque, 290 for the mosque related services). The rest is left with asphalt car parking and circulation. A summary of the mosque's details is listed in Table 8.25.



Site Plan



Plan

Figure 8.7 (A) The urban configuration of Al-Amodi mosque, showing the mosque in relation to its neighbours (upper) and the ground floor plan of the mosque (lower).

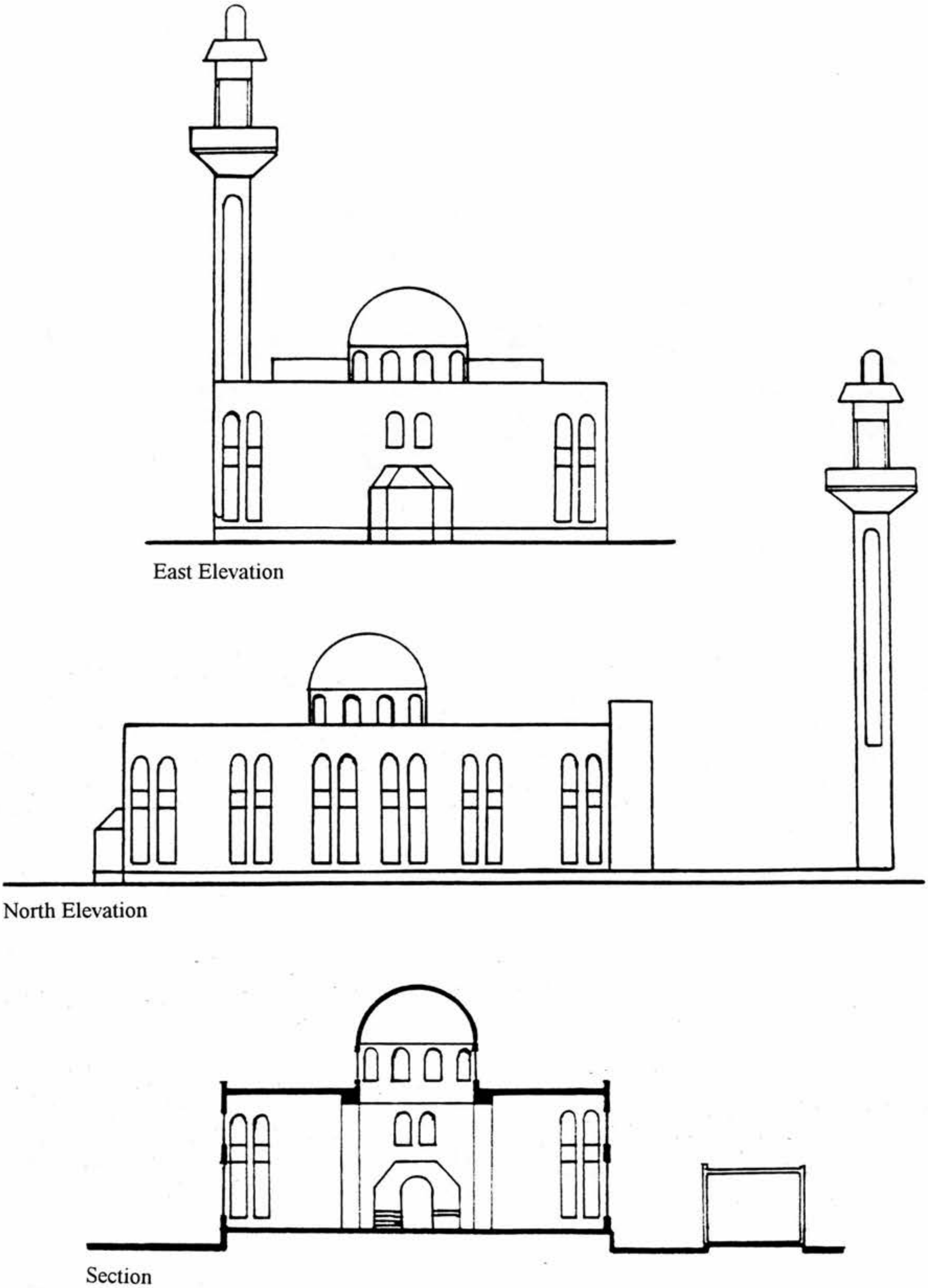


Figure 8.7 (B) East and north elevations and section of Al-Amodi mosque.

Table 8.25 Some details of Al-Amodi mosque

ITEMS	Al-Amodi
Dimensions	mosque
Plot size	4758 sq. m
Mosque area	758 sq. m
Mosque volume	6297 cub. m
Number of worshippers	972 person
Mosque services area	290 sq. m
U- Value (W/m^2 k)	
. External walls: 210 mm thick concrete block with 50 mm sand cement mortar and 20mm marble tiles	1.002
. Glazing: Single glazed windows	5.6
. Roof: Tiled reinforced concrete flat roof with plastered ceiling	2.922
. Floor: Reinforced concrete floor in contact with the earth, tiled and carpeted	1.13
Internal temperature	25°C
External temperature	36°C
Areas	
. Exposed prayer hall's walls to the outdoor environment	697 sq. m
. Glazing	104 sq. m
. Flat roof	657 sq. m

8.2.3.1.2 Energy, active and passive cooling systems used

Electricity is used in this mosque. The average monthly air conditioning energy consumption and the number of air conditioners involved are shown in Table 8.26. The annual average cooling energy consumption is approximately 64894 Kwh and the annual average energy base is about 33504 Kwh. The survey conducted on this mosque found many appliances of 2 water coolers, air conditioners, fans, sound amplifier, and 120 lights

The managers of this mosque use the split type air conditioning system and ceiling fans to cool the mosque. 10 split units are used; 2 in the female zone and 8 in the male prayer hall. These air conditioners are left always without proper maintenance and they are reinjected with refrigerant gas every 6 years. These cooling systems are put on 20 minutes prior to the call of the prayer and put off 15 minutes after the prayer has finished. The systems are used during the daily and Friday prayers, teaching of the Holy Quran between Magrib and Isha'a prayers, and special lectures delivered four times a month and last 30 minutes each.

The managers of this mosque have adopted some good measures to save energy. They minimise the infiltration inside the mosque and they make it very tidy. They naturally ventilate the mosque at night for two hours on daily basis. For the whole month of January, the cooling of mosque has been achieved by using natural ventilation. Unfortunately, the use of shading devices is totally eliminated.

8.2.3.1.3 The proposed strategy and the measures' performances

The results of the proposed passive cooling strategy and the measures potential savings are listed in Tables 8.27 and 8.28 (A, B, C, D, E and F) respectively.

Table 8.26 Average monthly air conditioning energy consumption (Kwh) and the number of air conditioners used in Amodi mosque.

Month	Air conditioning energy (Kwh)	Numbers of A/C units
January	0	0
February	1062	4
March	3180	6
April	4600	8
May	7188	8
June	9234	10
July	12186	10
August	10080	10
September	7220	8
October	6006	8
November	3137	6
December	1001	4

Table 8.27 The estimated potential reductions of the proposed passive cooling strategy in Amodi mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Thermal mass and air movement	52081.20	3072.79	2604	80.25	3.800	85.04	8.270	0.487	0.413	0.071

Table 8.28 (A) The estimated potential reductions of the proposed measure of night ventilation in Amodi mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Night Ventilation	2750	162.25	137.50	4.2	0.380	8.5	0.436	0.025	0.021	.003

Table 8.28 (B) The estimated potential reductions and payback periods of the proposed measure of complete shading existing windows in Amodi mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost 1 m^2 (SRi)	Pay back period (years)
Shading Windows	7640	450.78	382.02	11.77	0.327	7.31	72.94	4.303	3.647	0.619	65	15.1

Table 8.28 (C) The estimated potential reductions and payback periods of the proposed walls in Amodi mosque.

Wall Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	1.770	64894											
0	0.926	5960	351.6	298.0	9.18	0.163	3.65	8.552	0.504	0.427	0.073	25	58
1	0.541	8433	497.5	421.6	12.99	0.436	9.75	12.099	0.713	0.604	0.104	52	85
2	0.380	9456	557.9	472.8	14.57	0.599	13.41	13.566	0.800	0.678	0.116	52	76
3	0.293	10114	596.7	505.7	15.58	0.654	14.63	14.512	0.856	0.725	0.125	52	71
4	0.679	7471	440.7	373.5	11.51	0.327	7.31	10.720	0.632	0.536	0.092	67	125
5	0.444	9081	535.7	454.0	13.99	0.545	12.19	13.029	0.768	0.651	0.112	67	102
6	0.330	9923	585.4	496.1	15.29	0.654	14.63	14.237	0.839	0.711	0.122	67	94
7	0.664	7567	446.4	378.3	11.66	0.327	7.31	10.857	0.640	0.542	0.093	25	46

Table 8.28 (D) The estimated potential reductions and payback periods of the proposed roofs in Amodi mosque.

Roof Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	2.832	64894											
0	1.096	13742	810.7	687.1	21.17	0.872	19.50	20.917	1.234	1.045	0.180	40	38
1	0.892	15580	919.2	779.0	24.00	0.981	21.90	23.714	1.399	1.185	0.204	70	59
2	0.681	17269	1018.8	863.4	26.61	1.144	25.60	26.284	1.550	1.314	0.226	97	73
3	0.444	18967	1119.0	948.3	29.22	1.417	31.17	28.870	1.703	1.443	0.248	97	67
4	0.330	20082	1184.8	1004.0	30.94	1.471	32.90	30.566	1.803	1.528	0.263	97	63
5	0.794	16350	964.6	817.5	25.19	1.035	23.17	24.886	1.468	1.244	0.214	76	61
6	0.490	18797	1109.0	939.8	28.96	1.417	31.17	28.610	1.687	1.430	0.246	76	53
7	0.354	19884	1173.1	994.0	30.64	1.471	32.90	30.264	1.785	1.513	0.260	76	50

Table 8.28 (E) The estimated percentages of air conditioning energy reductions of the proposed measures in Amodi mosque

		R0	R1	R2	R3	R4	R5	R6	R7
		21.17	24	26.61	29.22	30.94	25.19	28.96	30.64
W0	9.18	30.35	33.18	35.79	38.4	40.12	34.37	38.14	39.82
W1	12.99	34.16	36.99	39.6	42.21	43.93	38.18	41.95	43.63
W2	14.57	35.74	38.57	41.18	43.79	45.51	39.76	43.53	45.21
W3	15.58	36.75	39.58	42.19	44.8	46.52	40.77	44.54	46.22
W4	11.51	32.68	35.51	38.12	40.73	42.45	36.7	40.47	42.15
W5	13.99	35.16	37.99	40.6	43.21	44.93	39.18	42.95	44.63
W6	15.29	36.46	39.29	41.9	44.51	46.23	40.48	44.25	45.93
W7	11.66	32.83	35.66	38.27	40.88	42.60	36.85	40.62	42.30

Table 8.28 (F) The estimated reductions and the payback periods under various combinations of modified roof and walls (namely giving higher saving percentages in air conditioning energy).

Roof Type	Wall Type	U- value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
4	3	0.623	30188	1781	1509.4	46.52	2.1250	47.50	45.078	2.659	2.253	0.388	149	66
4	6	0.660	30000	1770	1500.0	46.23	2.1250	47.50	44.804	2.643	2.240	0.386	164	73
7	3	0.647	29994	1769	1499.7	46.22	2.1250	47.50	44.777	2.641	2.238	0.386	128	57
7	6	0.684	29805	1758	1490.2	45.93	2.1250	47.50	44.501	2.625	2.225	0.383	143	64
4	2	0.710	29533	1742	1476.6	45.51	2.0710	46.34	44.132	2.603	2.206	0.380	149	67
7	2	0.734	29338	1730	1466.9	45.21	2.0165	45.12	43.830	2.585	2.191	0.377	128	58
4	5	0.774	29156	1720	1457.8	44.93	2.0165	45.12	43.595	2.572	2.179	0.375	164	75
3	3	0.737	29072	1715	1453.6	44.80	2.0165	45.12	43.382	2.559	2.169	0.373	149	68
7	5	0.798	28962	1708	1448.1	44.63	2.0165	45.12	43.293	2.554	2.164	0.373	143	66
6	3	0.783	28903	1705	1445.1	44.54	2.0165	45.12	43.122	2.544	2.156	0.371	128	59
3	6	0.774	28884	1704	1444.2	44.51	2.0165	45.12	43.107	2.543	2.155	0.371	164	76
6	6	0.820	28715	1694	1435.7	44.25	2.0165	45.12	42.847	2.527	2.142	0.369	143	66

8.2.3.2 Case study III-B: T. Lami Mosque

This mosque is the second mosque representing the third category of the central mosque type that has a moderate air conditioning energy consumption level. It is located in a low density high class residential community. The mosque is totally separated from neighbouring buildings.

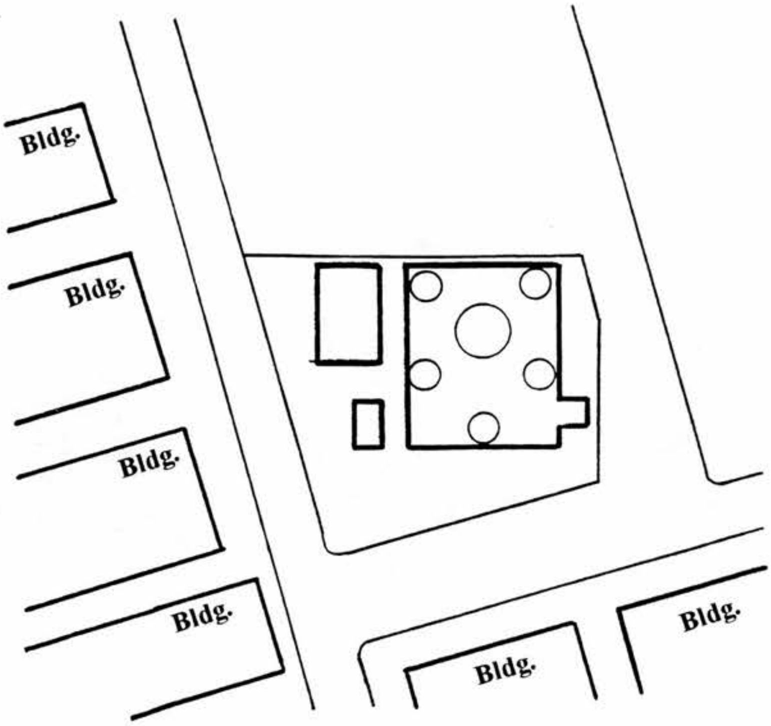
8.2.3.2.1 Mosque conditions

The mosque is a two storey high building designed to accommodate male men's prayer hall in the ground level and the women's prayer hall in a mezzanine floor. This mezzanine floor is designed at the back along the mosque and provided with private access from the south. The mosque dominates the north west part of the plot and is surrounded by paved open spaces. These paved areas increase the solar intensity around the mosque (figures 8.8 A and B).

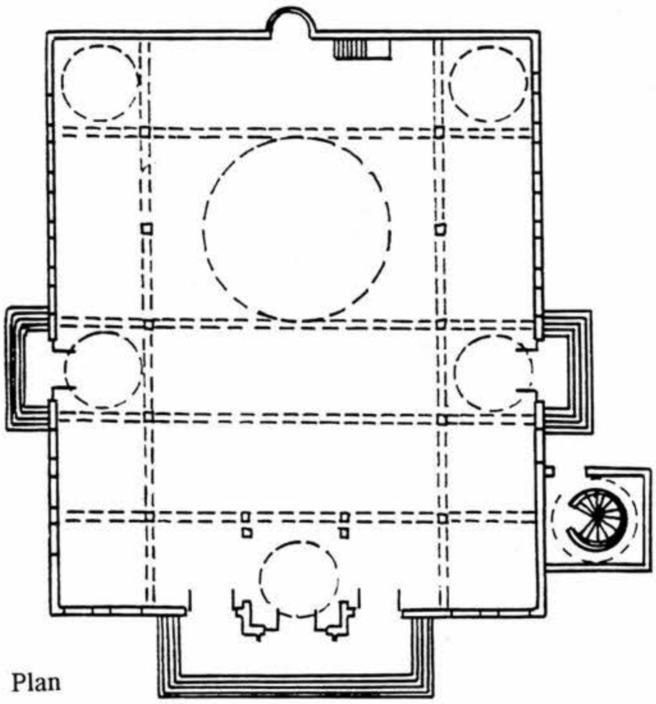
The mosque accommodates 755 worshippers of different ages. Only one sixth of the mosque is occupied during the daily prayers and fully occupied in the Friday prayer. The plot gross area is about 3906 square metres. The net of the built area is 750 square metres for the mosque, 32.48 square metres for the ablution area and 175 square metres for the residential quarter. A summary of the mosque's details is listed in Table 8.29.

8.2.3.2.2 Energy, active and passive cooling systems used

The energy type used in this mosque is similar to the energy used in mosques throughout the Kingdom. The energy type is electricity. Electricity is used for cooling



Site Plan



Plan

Figure 8.8 (A) The urban configuration of T. Lami mosque, showing the mosque in relation to its neighbours (upper) and the ground floor plan of the mosque (lower).

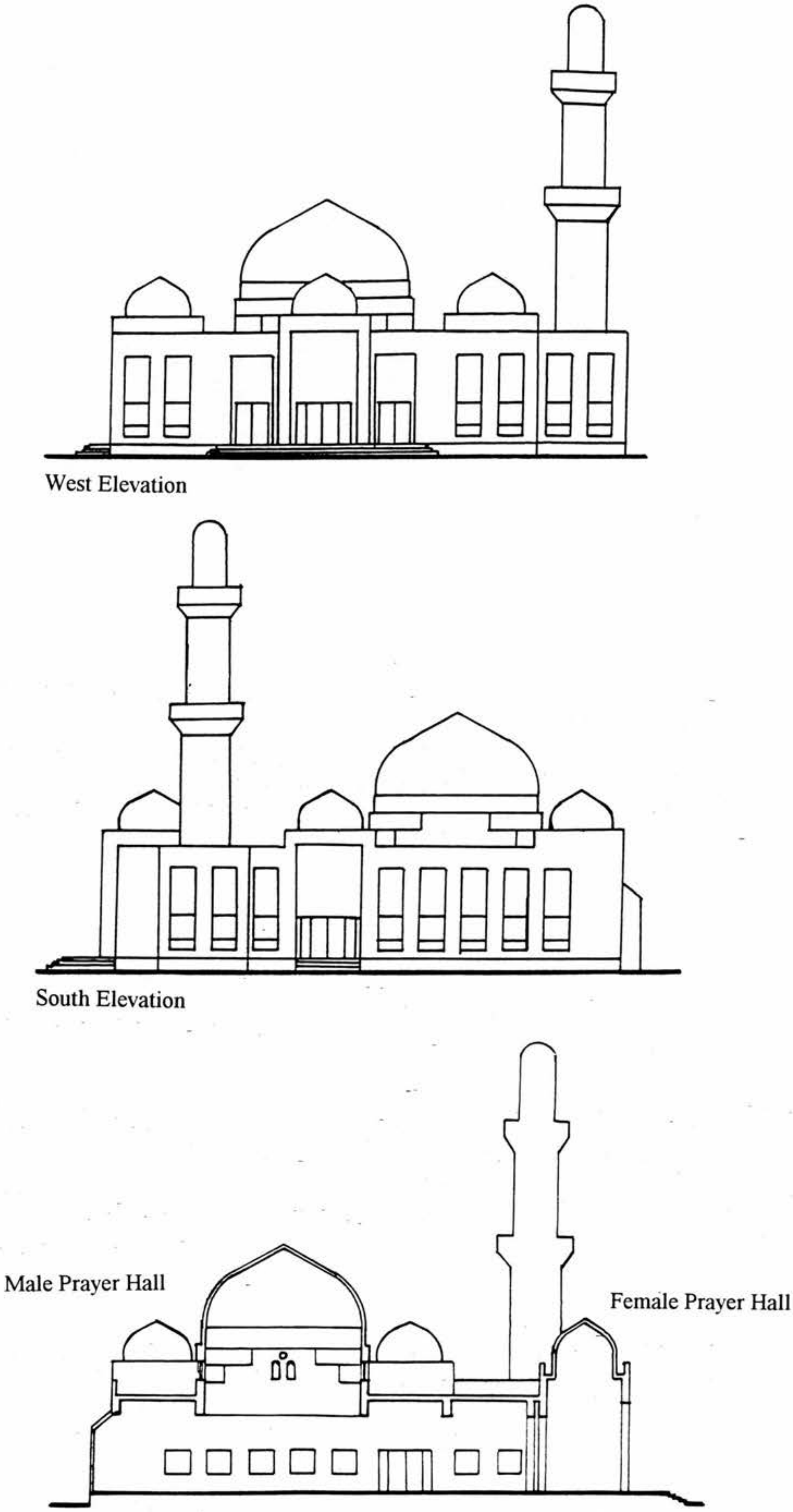


Figure 8.8 (B) South and West elevations and section of T. Lami mosque.

Table 8.29 Some details of T. Lami mosque

ITEMS	**T. Lami**
Dimensions	**mosque**
Plot size	3906 sq. m
Mosque area	750 sq. m
Mosque volume	5204 cub. m
Number of worshippers	755 person
Mosque services area	205 sq. m
U- Value (W/m^2 k)	
. External walls: 210 mm thick concrete block with 50 mm sand cement mortar and 20mm marble tiles	1.002
. Glazing: Single glazed windows	5.6
. Roof: Tiled reinforced concrete flat roof with plastered ceiling	2.922
. Floor: Reinforced concrete floor in contact with the earth, tiled and carpeted	1.13
Internal temperature	24°C
External temperature	37.5°C
Areas	
. Exposed prayer hall's walls to the outdoor environment	604 sq. m
. Glazing	60 sq. m
. Flat roof	615 sq. m

systems and other appliances and lights.

The managers of the mosque expressed their annoyance at the high energy consumption of the mosque. The average monthly air conditioning energy consumption and the number of air conditioners involved are shown in Table 8.30. Actually, the annual average amounts of energy used for cooling the mosque is approximately 119074 Kwh or 22.88 Kwh per cubic metre with the emission of 1.35 Kg of CO_2 gas. The different appliances available in the mosque are sound amplifier system, air conditioners, lights and 2 water cooler..

The mosque is cooled mechanically by a split floor type air conditioning system. The system consists of ten units of a medium size cooling capacity. The system is serviced four times annually and is reinjected with refrigerant every 5 years by a professional agent. The system are used for daily as well as Friday prayers and during the four special talks on monthly basis. The system is switched on 15 minutes prior to call of the prayer and shut down 20 to 30 minutes after the prayer has finished. The system are switched off for the whole month of January.

The managers of T. Lami mosque did many good efforts in saving energy. They use sun breakers on the windows. Furthermore, they use natural ventilation during the prayer times for most days of January. Finally, mosque is naturally ventilated 4 to 5 times a month for 1 to 2 hours during daytime when the mosque is not used.

<u>8.2.3.2.3 The proposed strategy and the measures' performances</u>

The results of the proposed passive cooling strategy and the measures potential savings are listed in Tables 8.31 and 8.32 (A, B, C, D, E and F) respectively.

Table 8.30 Average monthly air conditioning energy consumption (Kwh) and the number of air conditioners used in T. Lami mosque.

Month	Air conditioning energy (Kwh)	Numbers of A/C units
January	0	0
February	3839	6
March	7386	8
April	10124	8
May	14821	10
June	17033	10
July	18199	10
August	15544	10
September	13383	10
October	7929	8
November	6433	8
December	4383	8

Table 8.31 The estimated potential reductions of the proposed passive cooling strategy in T. Lami mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Thermal mass and air movement	98358.07	5803.12	4917.90	82.60	4.432	86.52	18.90	1.115	0.945	0.162

Table 8.32 (A) The estimated potential reductions of the proposed measure of night ventilation in T. Lami mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Night Ventilation	2273	134.10	113.65	1.90	0.0545	1.06	0.436	0.025	0.021	0.003

Table 8.32 (B) The estimated potential reductions and payback periods of the proposed measure of complete shading existing windows in T. Lami mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost 1 m^2 (SRi)	Pay back period (years)
Shading Windows	9591	565.83	479.58	8.055	0.163	3.19	157.64	9.299	7.877	1.349	65	8.251

Table 8.32 (C) The estimated potential reductions and payback periods of the proposed walls in T. Lami mosque.

Wall Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	1.770	119074											
0	0.926	5191	306	259.5	4.36	0	0	8.606	0.507	0.430	0.074	25	58
1	0.541	7358	434	367.9	6.18	0	0	12.174	0.718	0.608	0.104	52	85
2	0.380	8251	486	412.5	6.93	0	0	13.649	0.805	0.682	0.117	52	76
3	0.293	8823	520	441.1	7.41	0	0	14.601	0.861	0.730	0.125	52	71
4	0.679	6513	384	325.6	5.47	0	0	10.786	0.636	0.539	0.092	67	124
5	0.444	7918	467	395.9	6.65	0	0	13.109	0.773	0.655	0.113	67	102
6	0.330	8656	510	432.8	7.27	0	0	14.325	0.845	0.716	0.123	67	93
7	0.664	6604	389	330.2	5.54	0	0	10.924	0.644	0.546	0.094	25	45

Table 8.32 (D) The estimated potential reductions and payback periods of the proposed roofs in T. Lami mosque.

Roof Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	2.832	119074											
0	1.096	12859	758	642.9	10.8	0.272	5.31	20.913	1.233	1.045	0.180	40	38
1	0.892	14527	857	726.3	12.2	0.436	8.50	23.709	1.398	1.185	0.204	70	59
2	0.681	16074	948	803.7	13.5	0.599	11.70	26.279	1.550	1.313	0.226	97	73
3	0.444	17742	1046	887.1	14.9	0.599	11.70	29.033	1.712	1.451	0.250	97	66
4	0.330	18694	1102	934.7	15.7	0.599	11.70	30.561	1.803	1.528	0.263	97	63
5	0.794	15241	899	762.0	12.8	0.545	10.60	24.881	1.467	1.244	0.214	76	61
6	0.490	17503	1032	875.1	14.7	0.599	11.70	28.605	1.687	1.430	0.246	76	53
7	0.354	18575	1095	928.7	15.6	0.599	11.70	30.259	1.785	1.512	0.260	76	50

Table 8.32 (E) The estimated percentages of air condtioning energy reductions of the proposed measures in T. Lami mosque.

		R0	R1	R2	R3	R4	R5	R6	R7
		10.8	12.2	13.5	14.9	15.78	12.8	14.7	15.6
W0	4.36	15.16	16.56	17.86	19.26	20.14	17.16	19.06	19.96
W1	6.18	16.98	18.38	19.68	21.08	21.96	18.98	20.88	21.78
W2	6.93	17.73	19.13	20.43	21.83	22.71	19.73	21.63	22.53
W3	7.41	18.21	19.61	20.91	22.31	23.19	20.21	22.11	23.01
W4	5.47	16.27	17.67	18.97	20.37	21.25	18.27	20.17	21.07
W5	6.65	17.45	18.85	20.15	21.55	22.43	19.45	21.35	22.25
W6	7.27	18.07	19.47	20.77	22.17	23.05	20.07	21.97	22.87
W7	5.54	16.34	17.74	19.04	20.44	21.32	18.34	20.24	21.14

Table 8.32 (F) The estimated reductions and the payback periods under various combinations of modified roof and walls (namely giving higher saving percentages in air conditioning energy).

Roof Type	Wall Type	U- value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
4	3	0.623	27622	1629	1381.1	23.19	0.981	19.1	45.162	2.664	2.258	0.389	149	65
4	6	0.660	27456	1619	1372.8	23.05	0.981	19.1	44.886	2.648	2.244	0.386	164	73
7	3	0.647	27437	1618	1371.8	23.04	0.981	19.1	44.860	2.646	2.243	0.386	128	57
7	6	0.684	27270	1608	1363.5	22.90	0.981	19.1	44.584	2.630	2.229	0.384	143	64
4	2	0.710	27047	1595	1352.3	22.71	0.981	19.1	44.210	2.608	2.210	0.381	149	67
7	2	0.734	26861	1584	1343.0	22.55	0.981	19.1	43.908	2.590	2.195	0.378	128	58
4	5	0.774	26720	1576	1336.0	22.44	0.926	18.0	43.670	2.576	2.183	0.376	164	75
3	3	0.737	26682	1574	1334.1	22.40	0.926	18.0	43.634	2.574	2.181	0.376	149	68
7	5	0.798	26535	1565	1326.7	22.28	0.926	18.0	43.368	2.558	2.168	0.373	143	65
3	6	0.774	26516	1564	1325.8	22.26	0.926	18.0	43.358	2.558	2.167	0.373	164	75
6	3	0.783	26420	1558	1321.0	22.18	0.926	18.0	43.206	2.549	2.160	0.372	128	59
4	1	0.871	26155	1543	1307.7	21.96	0.872	17.0	42.735	2.521	2.136	0.368	149	69

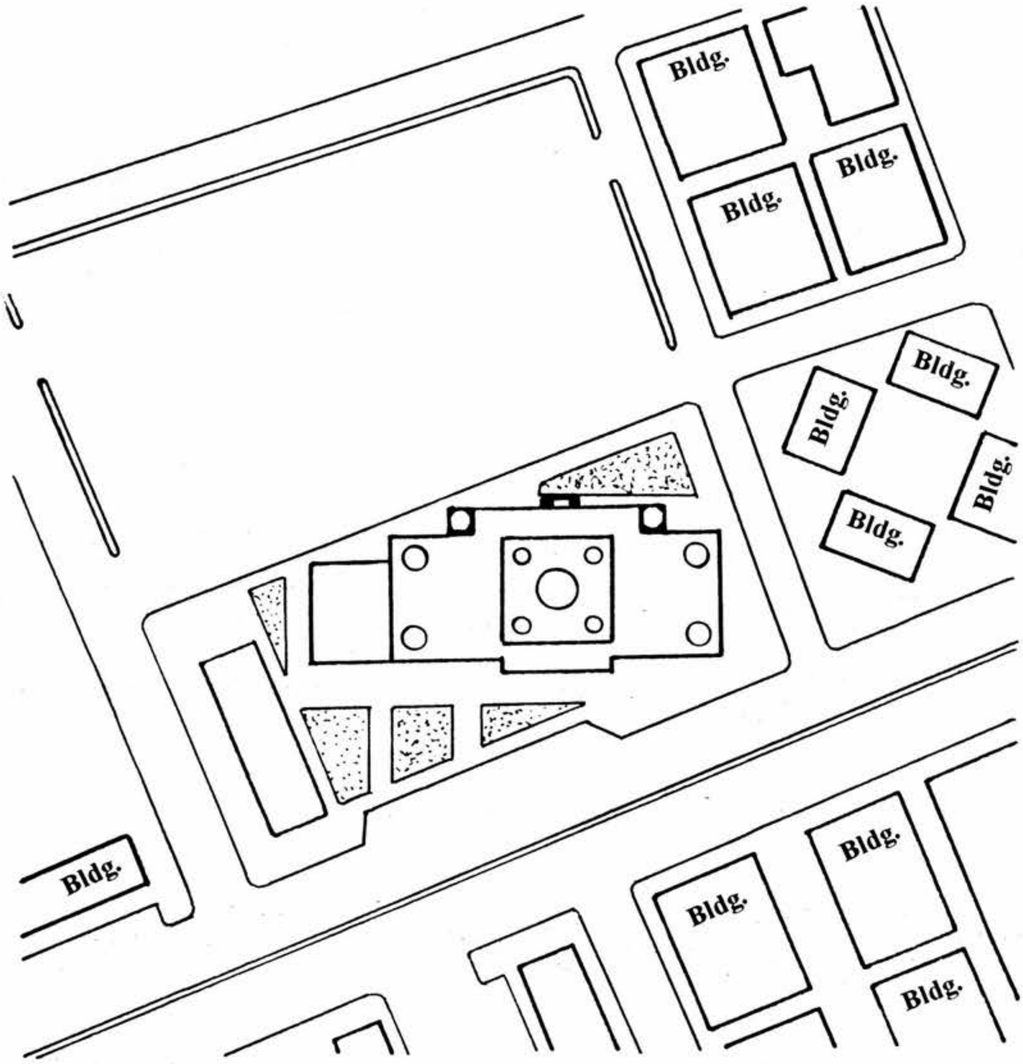
8.2.3.3 Case Study III-B: Al-Shaoibi Mosque

This case study is one of the two mosques which represent the third category of our surveyed mosques. The mosque is a two-storey building. It is surrounded by a major road from the west and three local streets from the other three sides. This major road is considered as one of the busiest road in Jeddah carrying a very large traffic volume. Moreover, a large car parking lot with an area of 5922 square metres is designed to the east of the mosque. Therefore, with such types of surrounding, heat environment around the mosque is expected to increase.

8.2.3.3.1 Mosque Condition

The mosque is located in Al-Salama residential district, and is set isolated from the neighbouring buildings and the Imam and Muaddin quarter. It consists of a ground level floor used as male prayer hall and first floor for female prayer hall in a mezzanine form. The mosque is mainly surrounded by paved open spaces which increase the solar intensity around the mosque. Very limited areas are covered by plantation (see figures 8.9 A, B and C).

The mosque can accommodate 1893 worshippers, 75% male and 25% female of different ages. Only a third of the mosque is usually occupied during Duhur and Asr prayers, fourth in Fajr prayer, and full in Magrib, Isha'a and Friday prayers. The gross plot area is approximately 10340 square metres. The net built area is 1485 square metres for the mosque, 282 square metres for the ablution service, and 350 square metres for the residential quarter. A 2301 square metres is left as open area around the mosque. A summary of the mosque's details is listed in Table 8.33.



Site Plan

Figure 8.9 (A) The urban configuration of Al-Shoaibi mosque, showing the mosque in relation to its neighbours.

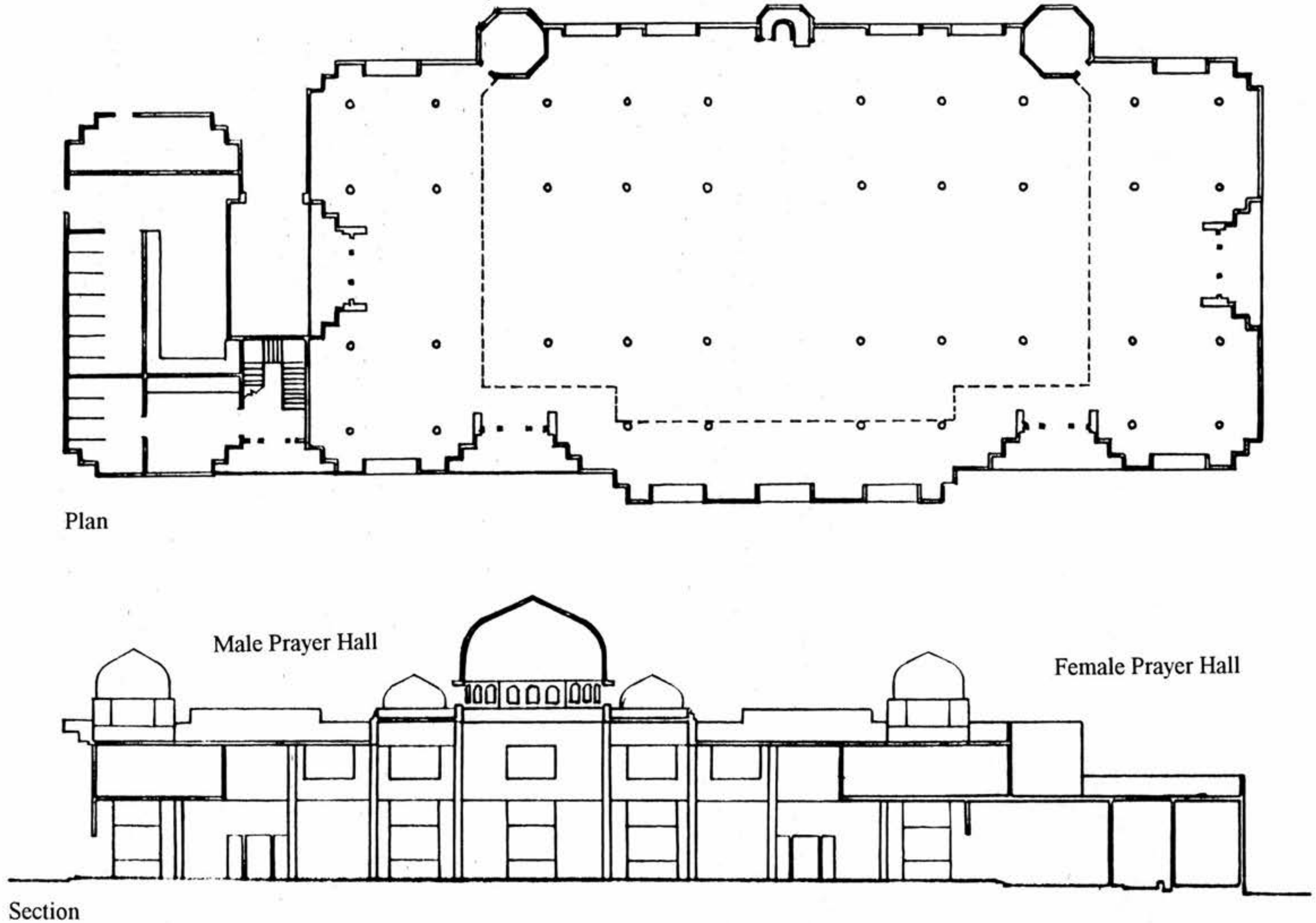


Figure 8.9 (B) The plan and section of Al-Shoaibi mosque.

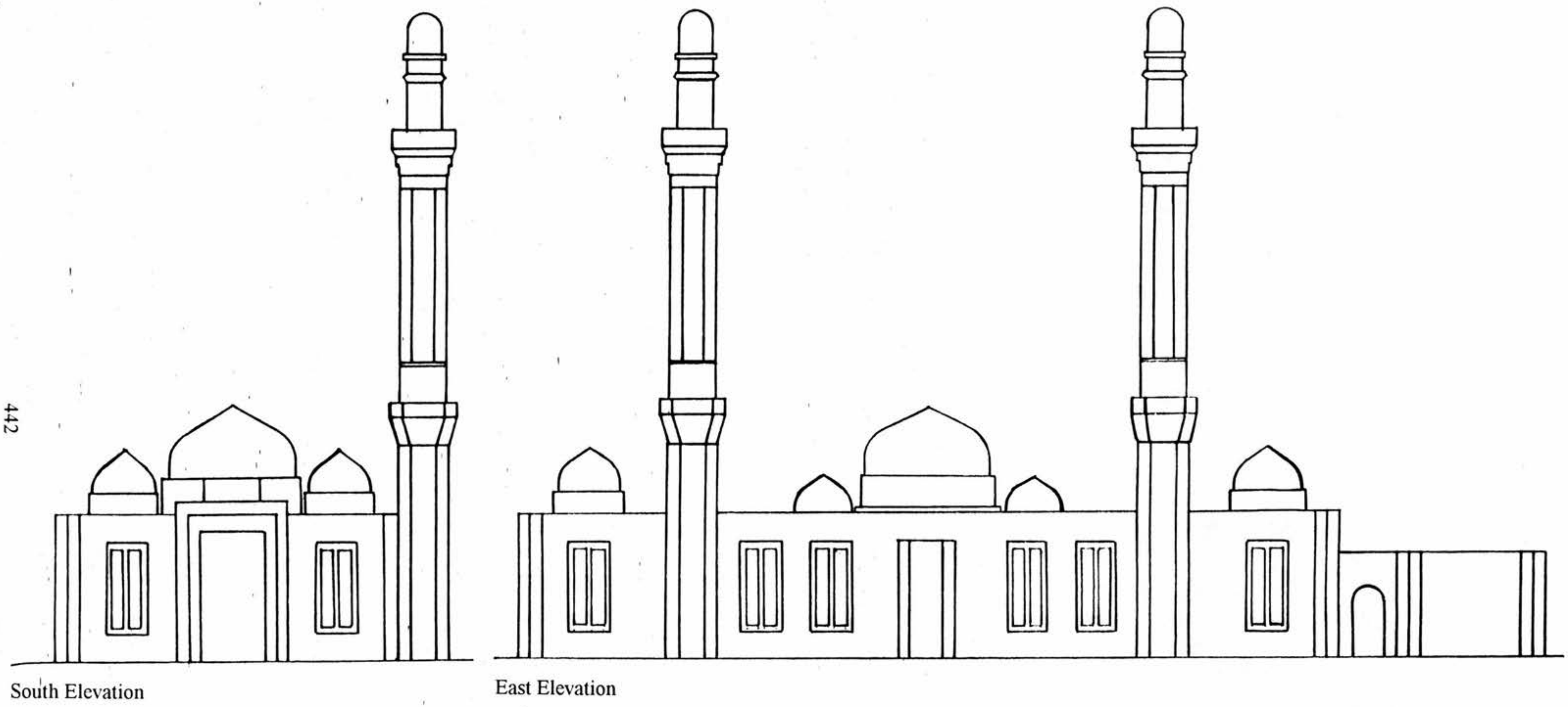


Figure 8.9 (C) South and east elevations of Al-Shoaibi mosque.

Table 8.33 Some details of Al-Shoaibi mosque

ITEMS	**Al-Shoaibi mosque**
Dimensions	
Plot size	10340 sq. m
Mosque area	1485 sq. m
Mosque volume	11488 cub. m
Number of worshippers	1893
Mosque services area	632 sq. m
U- Value (W/m^2 k)	
. External walls: 210 mm thick concrete block with 50 mm sand cement mortar and 20mm marble tiles	1.002
. Glazing: Single glazed windows	5.6
. Roof: Tiled reinforced concrete flat roof with plastered ceiling	2.922
. Floor: Reinforced concrete floor in contact with the earth, tiled and carpeted	1.13
Internal temperature	23°C
External temperature	37.5°C
Areas	
. Exposed prayer hall's walls to the outdoor environment	1120 sq. m
. Glazing	107 sq. m
. Flat roof	1211 sq. m

8.2.3.3.2 Energy, active and passive cooling systems used

The energy used in this mosque is electricity and it is used for the cooling systems and appliances. The average monthly air conditioning energy consumption and the number of air conditioners involved are shown in Table 8.34. The average annual energy consumption for this mosque is about 623085 Kwh of which about 75% (467341 Kwh is consumed as air conditioning energy. The remaining 25% is used by the other appliances. The annual average air conditioning energy consumption is approximately 40 Kwh per cubic metre which is responsible of emitting 2.4 Kg of CO_2 gas. The appliances found in this mosque are 10 water coolers of 1.8 cubic feet, 500 lights, sound amplifier, and air conditioners.

The cooling system used in this mosque is the central air conditioning system. Nine units of 120 tons is placed on the roof. The system is well serviced by a professional firm once a year and reinjected with refrigerant gas every 5 to 6 years. The system is normally puts on 45 minutes to one hour prior to the call of the prayer and shut down 15 to 30 minutes after the prayer has finished. The system is used during the daily and Friday prayers, teaching the Holy Quran between Magrib and Isha'a prayers, and four monthly lectures lasts for 30 minutes each.

The high energy consumption sometimes encourages people to put some effort into saving energy, money and the environment by emitting less toxic gases. Unfortunately, the managers of his mosque did not make a noticeable effort partly because they can afford to pay for it. They restricted their effort in reducing infiltration in the mosque and using reflective glass protected with some mosaic works acting as sun breakers. Moreover, they use natural ventilation two to three times a month for 30 minutes after the Friday prayer.

8.2.3.3.3 The proposed strategy and the measures' performances

The results of the proposed passive cooling strategy and the measures potential savings are listed in Tables 8.35 and 8.36 (A, B, C, D, E and F) respectively.

Table 8.34 Average monthly air conditioning energy consumption (Kwh) and the number of air conditioners used in Shoaibi mosque.

Month	Air conditioning energy (Kwh)	Numbers of A/C units	Numbers of A/C units
January	0	0	0
February	34521	6	0
March	36421	6	0
April	39732	8	0
May	47340	8	0
June	50633	8	1
July	59669	8	1
August	48137	8	1
September	46297	8	0
October	41048	8	0
November	36669	6	0
December	26857	6	0

Table 8.35 The estimated potential reductions of the proposed passive cooling strategy in Shoaibi mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Thermal mass and air movement	401440.1	23684.97	20072.01	85.90	5.980	86.04	34.944	2.061	1.747	0.301

Table 8.36 (A) The estimated potential reductions of the proposed measure of night ventilation in Shoaibi mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
Night Ventilation	5018	296.06	250.90	1.07	0	0	0.436	0.025	0.021	.0036

Table 8.36 (B) The estimated potential reductions and payback periods of the proposed measure of complete shading existing windows in Shoaibi mosque

	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost 1 m^2 (SRi)	Pay back period (years)
Shading Windows	19493	1150	974.66	4.17	0	0	182.16	10.74	9.09	1.458	65	7.14

Table 8.36 (C) The estimated potential reductions and payback periods of the proposed walls in Shoaibi mosque.

Wall Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	1.770	467324											
0	0.926	9943	586.6	497.1	2.12	0	0	8.878	0.523	0.443	0.076	25	56
1	0.541	14059	829.4	702.9	3.00	0	0	12.553	0.740	0.627	0.108	52	82
2	0.380	15761	929.8	788.0	3.37	0	0	14.072	0.830	0.703	0.121	52	73
3	0.293	16861	994.7	843.0	3.60	0	0	15.055	0.888	0.752	0.129	52	69
4	0.679	12265	723.6	613.2	2.62	0	0	10.951	0.646	0.547	0.094	67	122
5	0.444	15139	893.2	756.9	3.23	0	0	13.517	0.797	0.675	0.116	67	99
6	0.330	16545	976.1	827.2	3.54	0	0	14.772	0.871	0.738	0.127	67	90
7	0.664	12615	744.2	630.7	2.69	0	0	11.263	0.664	0.563	0.097	25	44

Table 8.36 (D) The estimated potential reductions and payback periods of the proposed roofs in Shoaibi mosque.

Roof Type	U-value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
	2.832	467324											
0	1.096	25329	1494.4	1266	5.42	0	0	20.915	1.233	1.045	0.180	40	38
1	0.892	28715	1694.1	1435	6.14	0	0	23.712	1.399	1.185	0.204	70	59
2	0.681	31828	1877.8	1591	6.81	0	0	26.283	1.550	1.314	0.226	97	73
3	0.444	35163	2074.6	1758	7.52	0	0	29.036	1.713	1.451	0.250	97	66
4	0.330	37014	2183.8	1850	7.92	0	0	30.564	1.803	1.528	0.263	97	63
5	0.794	30135	1777.9	1506	6.44	0	0	24.885	1.468	1.244	0.214	76	61
6	0.490	34645	2044.0	1732	7.41	0	0	28.609	1.687	1.430	0.246	76	53
7	0.354	36648	2162.2	1832	7.84	0	0	30.263	1.785	1.513	0.260	76	50

Table 8.36 (E) The estimated percentages of air conditioning energy reductions of the proposed measures in Shoaibi mosque

		R0	R1	R2	R3	R4	R5	R6	R7
		5.42	6.14	6.81	7.52	7.92	6.44	7.41	7.84
W0	2.12	7.54	8.26	8.93	9.64	10.04	8.56	9.53	9.96
W1	3.00	8.42	9.14	9.81	10.52	10.92	9.44	10.41	10.84
W2	3.37	8.79	9.51	10.18	10.89	11.29	9.81	10.78	11.21
W3	3.60	9.02	9.74	10.41	11.12	11.52	10.04	11.01	11.44
W4	2.62	8.04	8.76	9.43	10.14	10.54	9.06	10.03	10.46
W5	3.23	8.65	9.37	10.04	10.75	11.15	9.67	10.64	11.07
W6	3.54	8.96	9.68	10.35	11.06	11.46	9.98	10.95	11.38
W7	2.69	8.11	8.83	9.50	10.21	10.61	9.13	10.10	10.53

Table 8.36 (F) The estimated reductions and the payback periods under various combinations of modified roof and walls (namely giving higher saving percentages in air conditioning energy).

Roof Type	Wall Type	U- value	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost /m^2 (SRi)	Pay back period (years)
4	3	0.623	53835	3176	2691.7	11.52	0.082	1.1	45.620	2.691	2.281	0.393	149	65
4	6	0.660	53555	3159	2677.7	11.46	0.082	1.1	45.337	2.674	2.266	0.390	164	72
7	3	0.647	53461	3154	2673.0	11.44	0.082	1.1	45.318	2.673	2.265	0.390	128	56
7	6	0.684	53181	3137	2659.0	11.38	0.082	1.1	45.035	2.657	2.251	0.388	143	63
4	2	0.710	52760	3112	2638.0	11.29	0.082	1.1	44.636	2.633	2.231	0.384	149	66
7	2	0.734	52387	3090	2619.3	11.21	0.082	1.1	44.335	2.615	2.216	0.382	128	57
4	5	0.774	52106	3074	2605.3	11.15	0.082	1.1	44.081	2.600	2.204	0.380	164	74
3	3	0.737	51966	3066	2598.3	11.12	0.082	1.1	44.091	2.601	2.204	0.380	149	67
7	5	0.798	51732	3052	2586.6	11.07	0.082	1.1	43.780	2.583	2.189	0.377	143	65
3	6	0.774	51686	3049	2584.3	11.06	0.082	1.1	43.808	2.584	2.190	0.377	164	74
6	3	0.783	51452	3035	2572.6	11.01	0.082	1.1	43.664	2.576	2.183	0.376	128	58
6	6	0.820	51172	3019	2558.6	10.95	0.082	1.1	43.381	2.559	2.169	0.373	143	65

8.3 The proposed passive cooling strategy and the measures potential savings

The objectives of this section are to (1) discuss the proposed passive cooling strategy and the measures savings in all nine mosque categories and to (2) use the results in (a) producing the potential savings tables which can be used by the architect in calculating the different savings in any mosque with a selected measure and (b) estimating the potential savings of each measure and the passive cooling strategy when applied to all Jeddah existing air conditioned mosques as well as their contribution to the national air conditioning energy and CO_2 and CFCs emissions levels.

8.3.1 The passive cooling strategy performances in all mosque

The savings in air conditioning energy, money, CO_2 emissions and CFCs emissions amounts by adopting the strategy developed in Chapter Three is shown in table 8.37.

The results show that there are savings in air conditioning energy, money and CO_2 emission of 79.51% in Zaid, 81.41% in Majd, 84.15% in Forkan, 83.4% in Rida, 80.45% in Ibn Abbas, 81.59% in Taqwa, 80.25% in Amodi, 82.6% in T. Lami and 85.9% in Shoaibi mosque. In addition, the results indicated that there were high savings in CFCs emissions in all mosque categories of 86.34%, 85.47%, 84.24%, 86.28%, 82.82%, 87.11%, 85.04%, 86.52% and 86.04% respectively.

8.3.2 The measures performances in all mosque categories

8.3.2.1 Night ventilation

The savings in air conditioning energy, money, CO_2 emissions and CFCs emissions amounts by using night ventilation for 7 hours is shown in table 8.38.

Table 8.37 Passive cooling strategy savings under different mosque categories.

Mosque type	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
I-A	12110.93	714.54	605.54	79.51	2.03	86.34	8.063	0.475	.403	.069
I-B	38607.13	2277.82	1930.35	81.41	2.504	85.47	20.730	1.223	1.036	0.178
I-C	61158.27	3608.33	3057.91	84.15	2.907	84.24	31.41	1.853	1.57	.27
II-A	38466.87	2269.54	1923.34	83.4	2.70	86.28	9.968	0.588	0.498	0.085
II-B	72961.93	4304.75	3648.09	80.45	2.830	82.82	19.363	1.142	0.968	0.166
II-C	86410.33	5098.20	4320.51	81.59	3.590	87.11	35.899	2.118	1.794	0.309
III-A	52081.20	3072.79	2604	80.25	3.800	85.04	8.270	0.487	0.413	0.071
III-B	98358.07	5803.12	4917.90	82.60	4.432	86.52	18.90	1.115	0.945	0.162
III-C	401440.1	23684.97	20072.01	85.90	5.980	86.04	34.944	2.061	1.747	0.301

Table 8.38 Night ventilation savings under different mosque categories.

Mosque type	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^3 (Kwh)	CO_2 emisn. saved /m^3 (Kg)	Money saved /m^3 (SRi)	Money saved /m^3 (£)
I-A	656	38.70	32.8	4.3	0.112	4.7	0.436	0.025	0.021	0.003
I-B	813	47.96	40.65	1.71	0	0	0.436	0.025	0.021	0.003
I-C	841	49.619	42.05	1.10	0	0	0.432	0.025	0.021	0.003
II-A	1685	99.415	84.25	3.6	0	0	0.436	0.025	0.021	0.003
II-B	1646	97.114	82.30	1.81	0	0	0.436	0.025	0.021	0.003
II-C	1051	62.00	52.55	0.90	0	0	0.436	0.025	0.021	0.003
III-A	2750	162.25	137.50	4.2	0.380	8.5	0.436	0.025	0.021	0.003
III-B	2273	134.10	113.65	1.90	0.0545	1.06	0.436	0.025	0.021	0.003
III-C	5018	296.06	250.90	1.07	0	0	0.436	0.025	0.021	0.003

Figure 8.10 shows a relationship between air conditioning energy, money and CO_2 emission amounts and mosque volume where the decrease in mosque volume is associated with a decrease in savings.

The table shows that there are low savings in air conditioning energy, money and CO_2 emission in all mosques when applying night ventilation for the whole night. The savings were 4.3% in Zaid, 1.71% in Majd, 1.10% in Forkan, 3.6% in Rida, 1.81% in Ibn Abbas, 0.9% in Taqwa, 4.2% in Amodi, 1.9% in T. Lami and 1.07% in Shoaibi. The results also indicated that there were limited savings in CFCs emission in few mosque; 4.7% in Zaid, 8.5% in Amodi and 1.06% in T. Lami mosques. Although the levels of savings tend to be low when applying this measure, these savings can be achieved at no cost at all.

8.3.2.2 Complete shading of existing windows

The savings of complete shading of existing windows in all nine mosques is presented in table 8.39. The results shows that there are savings in air conditioning energy, money and CO_2 emission. These savings were 17.95% in Zaid, 6.53% in Majd, 5.59% in Forkan, 16.96% in Rida, 6.23% in Ibn Abbas, 4.76% in Taqwa, 11.77% in Amodi, 8.05% in Lami and 4.7% in Shoaibi. The CFCs emissions savings were 11.9% in Zaid, 7.4% in Rida, 7.31% in Amodi and 3.19% in Lami. There was no savings in CFCs emission in Majd, Forkan, Ibn Abbas, Taqwa and Shoaibi mosques.

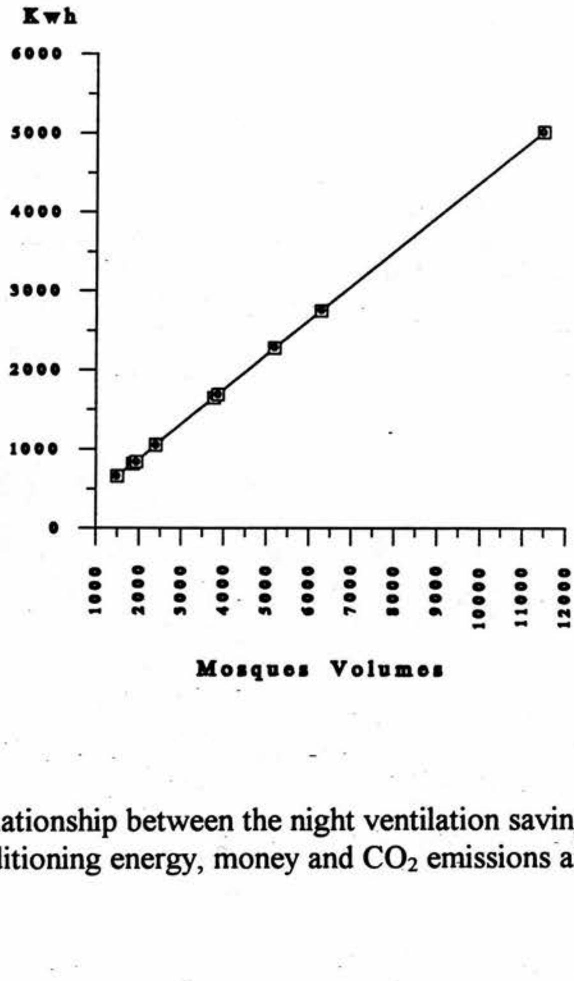


Figure 8.10 A relationship between the night ventilation savings as related to air conditioning energy, money and CO_2 emissions and mosque volume.

Table 8.39 The savings of complete shading of existing windows in all nine mosques categories.

Mosque type	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved	CFCs emisn. saved (Kg)	% of CFCs saved	AC. energy saved /m^2 (Kwh)	CO_2 emisn. saved /m^2 (Kg)	Money saved /m^2 (SRi)	Money saved /m^2 (£)	Cost 1 m^2 (SRi)	Pay back period (years)
I-A	2735	161.36	136.75	17.95	0.28	11.9	173.59	10.229	8.67	1.495	65	7.5
I-B	3099	182.9	154.99	6.537	0	0	161.45	9.518	8.05	1.385	65	8.06
I-C	4066	239.91	203.32	5.59	0	0	155.489	9.172	7.76	1.331	65	8.36
II-A	7822	461.54	391.14	16.96	0.232	7.4	170.989	10.083	8.53	1.458	65	7.61
II-B	5652	333.51	282.64	6.23	0	0	158.11	9.318	7.89	1.276	65	8.23
II-C	5051	298.01	252.55	4.76	0	0	180.38	10.631	9.0	1.549	65	7.21
III-A	7640	450.78	382.02	11.773	0.327	7.31	72.94	4.303	3.64	1.619	65	15.1
III-B	9591	565.83	479.58	8.055	0.163	3.19	157.64	9.299	7.87	1.349	65	8.25
III-C	19493	115.09	974.66	4.17	0	0	182.16	10.74	9.09	1.567	65	7.14

8.3.2.3 Building and insulation materials for existing walls and roof

8.3.2.3.1 Proposed walls and the potential savings in air conditioning energy, money, CO_2 emissions, and CFCs emissions in all mosque categories

The savings in air conditioning energy, money, CO_2 emissions and CFCs emissions amounts by using the eight different proposals in all nine mosques is shown in table 8.40. Figure 8.11 shows a relationship between air conditioning energy, money, CO_2 emissions and CFCs emissions amounts and the different wall U-values, where the decrease in wall U-value is associated with an increase in air conditioning energy, money, CO_2 emissions for all the proposals in all nine mosques of the three mosques types and a decrease in CFCs emissions for most of the proposals in only three mosques of Zaid, Rida and Amodi.

A. Calcium silicate blocks (W0)

The results revealed that in using calcium silicate blocks (W0) attached to the existing wall of the nine mosques of Zaid, Majd, Forkan, Rida, Ibn Abbas, Taqwa, Amodi, T. Lami and Shoaibi mosques a possible air conditioning, money and CO_2 emission saving of about 13.49%, 7.43%, 3.30%, 12.09%, 5.33%, 2.86%, 9.18%, 4.36% and 2.12% respectively with CFCs emissions saving of 3.65% in Amodi mosque can be achieved.

B. The cavity wall with calcium silicate blocks (W7)

By applying the cavity wall covered with calcium silicate block (W7) the air conditioning energy, money and CO_2 saving were 9.45%, 4.19%, 15.34%, 6.76%, 3.63%, 11.66%, 5.54%, and 2.69% respectively. There were contributions to saving

Table 8.40 The different savings in air conditioning energy, money, CO_2 emission, CFCs emissions, and payback period by using various proposed building and insulation materials in existing walls

1. Air conditioning energy, money and CO_2 emission savings (%)

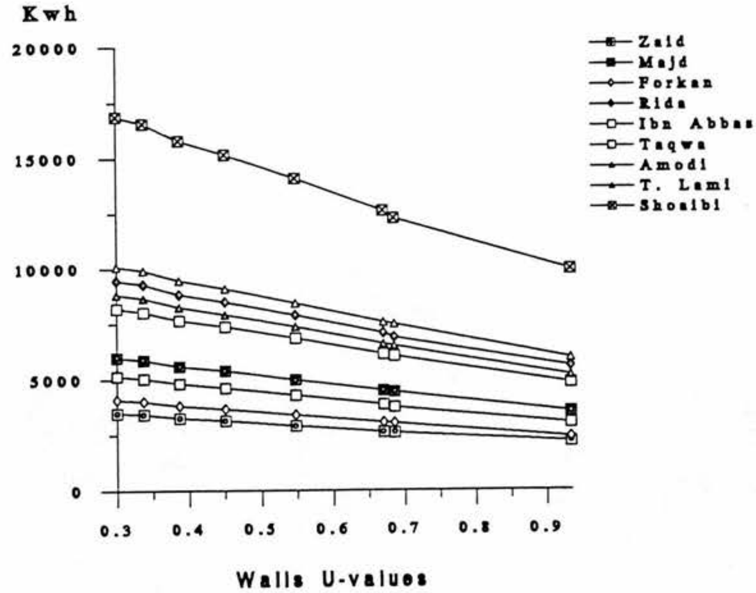
wall	U-value	Zaid	Majd	Forkan	Rida	Ibn Abbas	Taqwa	Amodi	T.Lami	Shoaibi
0	0.926	13.49	7.43	3.30	12.09	5.33	2.86	9.18	4.36	2.12
1	0.541	19.09	10.52	4.67	17.10	7.54	4.04	12.99	6.18	3.00
2	0.380	21.40	11.79	5.24	19.17	8.45	4.53	14.57	6.93	3.37
3	0.293	22.89	12.62	5.60	20.51	9.04	4.85	15.58	7.41	3.60
4	0.679	16.91	9.32	4.14	14.92	6.68	3.53	11.51	5.47	2.62
5	0.444	20.55	11.33	5.03	18.42	8.12	4.36	13.99	6.65	3.23
6	0.330	22.46	12.38	5.50	20.12	8.87	4.76	15.29	7.27	3.54
7	0.664	17.12	9.45	4.19	15.34	6.76	3.63	11.66	5.54	2.69

2. CFCs emissions saving (%)

wall	U-value	Zaid	Majd	Forkan	Rida	Ibn Abbas	Taqwa	Amodi	T.Lami	Shoaibi
0	0.926	0.00	0	0	0.00	0	0	3.65	0	0
1	0.541	11.90	0	0	3.70	0	0	9.75	0	0
2	0.380	16.60	0	0	7.41	0	0	13.41	0	0
3	0.293	19.00	0	0	14.82	0	0	14.63	0	0
4	0.679	2.30	0	0	0.00	0	0	7.31	0	0
5	0.444	14.20	0	0	7.41	0	0	12.19	0	0
6	0.330	19.04	0	0	12.97	0	0	14.63	0	0
7	0.664	2.30	0	0	0.00	0	0	7.31	0	0

3. Payback period (Years)

wall	Zaid	Majd	Forkan	Rida	Ibn Abbas	Taqwa	Amodi	T.Lami	Shoaibi
0	55	58	58	57	57	57	58	58	56
1	80	85	85	84	84	84	85	85	83
2	72	76	76	75	75	75	76	76	73
3	67	71	71	70	70	70	71	71	69
4	117	124	124	125	123	124	125	124	122
5	96	102	102	101	101	100	102	102	99
6	88	93	93	92	92	92	94	93	90
7	44	46	46	46	46	46	47	46	45



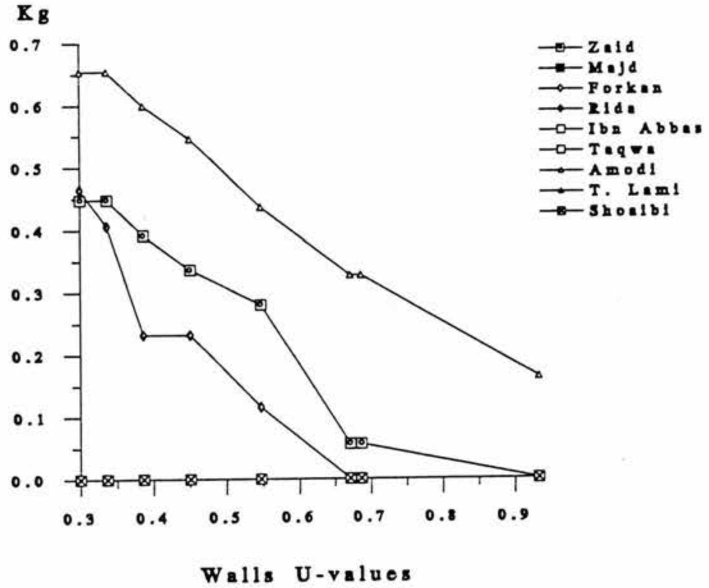


Figure 8.11 The positive relationships between savings in air conditioning energy, money, CO_2 emissions and CFCs emissions and the different wall U-values.

in CFCs emissions of 2.3% in Ibn Abbas mosque.

C Extruded polystyrene with calcium silicate blocks (W1, W2, W3)

The results reveal that by adopting the insulation material of extruded polystyrene of various thickness with calcium silicate blocks (W1, W2, W3), the possible saving in air conditioning energy and CO_2 emissions of about 19.09%, 21.40%, 21.4%, 22.89% in Zaid mosque, 10.52%, 11.79%, 12.62% in Majd mosque, 4.67%, 5.24%, and 5.6% in Forkan mosque, 17.10%, 19.17% and 20.51% in Rida mosque, 7.54%, 8.45%, 9.04% in Ibn Abbas mosque, 4.04%, 4.53% and 4.85% in Taqwa mosque, 12.99% 14.57% and 15.58% in Amodi mosque, 6.18%, 6.93%, 7.41% in T. Lami mosque and 3%, 3.37 and 3.6% in Shoaibi mosque. A reduction of CFCs emissions was found about 11.9%, 16.6% and 19% in Zaid mosque, 3.70%, 7.41% and 14.82% in Rida mosque and 9.75%, 13.41% and 14.63% in Amodi mosque. There was no contributions to saving in CFCs emissions in Majd, Forkan, Ibn Abbas, Taqwa, T. Lami and Shoaibi mosques.

D Extruded polystyrene with plaster board (W4, W5, W6)

The results shows that by using extruded polystyrene with plaster board a possible air conditioning energy, money and CO_2 emissions savings of about 16.91%, 20.55% and 22.46% in Zaid mosque, 9.32%, 11.33%, 12.38% in Majd mosque, 4.14%, 5.03% and 5.50% in Forkan mosque, 14.92%, 18.42% and 20.12% in Rida mosque, 6.68%, 8.12%, 8.87% in Ibn Abbas mosque, 3.53%, 4.36% and 4.76% in Taqwa mosque, 11.51%, 13.99% and 15.29% in Amodi mosque, 5.47%, 6.65%, 7.27% in T. Lami mosque and 2.62%, 3.23% and 3.54% in Shoaibi mosque can be achieved. As for the CFCs saving, a reduction of 2.3%, 14.2% and 19.04% in Zaid mosque, 7.41% and 12.97% in Rida mosque and 7.31%, 12.19% and 14.63% in Amodi mosque can be achieved. No CFCs emission savings from these proposed walls W4, W5 and W6 were found when applied in the six mosques of Majd, Forkan, Ibn Abbas, Taqwa, T. Lami and Shoaibi mosques.

E. Extruded polystyrene with either calcium silicate block (W3) or plaster board (W6)

By using extruded polystyrene with either calcium silicate blocks (W3) or plaster board (W6), highest savings in air conditioning energy, money, CO_2 emissions, and CFCs emissions can be achieved compared with the other types of walls. A possible reduction is found to be about 22.89% and 22.46% in Zaid, 12.62% and 12.38% in Majd, 5.6% and 5.5% in Forkan mosque, 20.51% and 20.12% in Rida mosque, 9.04% and 8.87% in Ibn Abbas mosque, 4.85% and 4.76% in Taqwa mosque, 15.58% and 15.29% in Amodi mosque, 7.41% and 7.27% in T. Lami mosque and 3.6% and 3.54% in Shoaibi mosque for air conditioning energy, money and CO_2 emissions associated and as high as 19% and 19.04% in Zaid mosque, 14.82% and 12.97% in Rida and 14.63% in Amodi mosque for CFCs emissions.

F. The cost effective analysis of the proposed walls

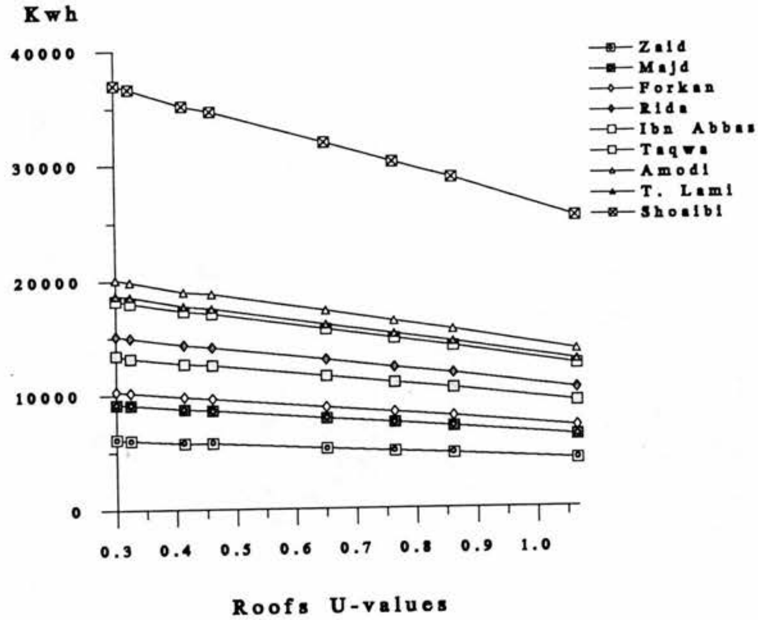
The pay back period for the proposed measures for walls are also listed in the table. Figures in the table does not specify or even indicate the optimum wall type to be used. This is due to the fact that the overall savings are very much dependent on the life of the building, the length of time that the occupant will stay in the mosque, and the minimum requirement of the building regulation. Nevertheless, the figure does show long period of pay back for all the simulated wall types and in all mosques as follows; 56 to 58 years for W0, 82 to 85 years for W1, 73 to 76 years for W2, 67 to 71 years for W3, 122 to 125 years for W4, 99 to 102 years for W5, 90 to 94 years for W6 and 44 to 46 years for W7. This is an indication that they are not cost effective, bearing in mind that one may be more effective than another, depending on the initial cost, the annual savings, and the overall use of the proposed element.

8.3.2.3.2 Proposed roofs and the potential savings in air conditioning energy, money, CO_2 emissions, and CFCs emissions in all mosque categories

The effect of modifying the existing roof, with utilising different ceiling types, of the nine case study mosques are presented graphically in figure 8.12. The figure shows that there is a positive relationship between U-values and the estimated savings in air conditioning energy, CO_2 emissions, and CFCs emissions. The results of the roof simulation is presented in Table 8.41.

A. Cavity ceiling with plaster board (C0)

The results revealed that by using cavity ceiling with plaster board (C0) one can save about 27.46% in Zaid mosque, 13.22% in Majd, 9.66% in Forkan mosque, 22.4% in Rida mosque, 13.74% in Ibn Abbas mosque, 8.66% in Taqwa mosque,



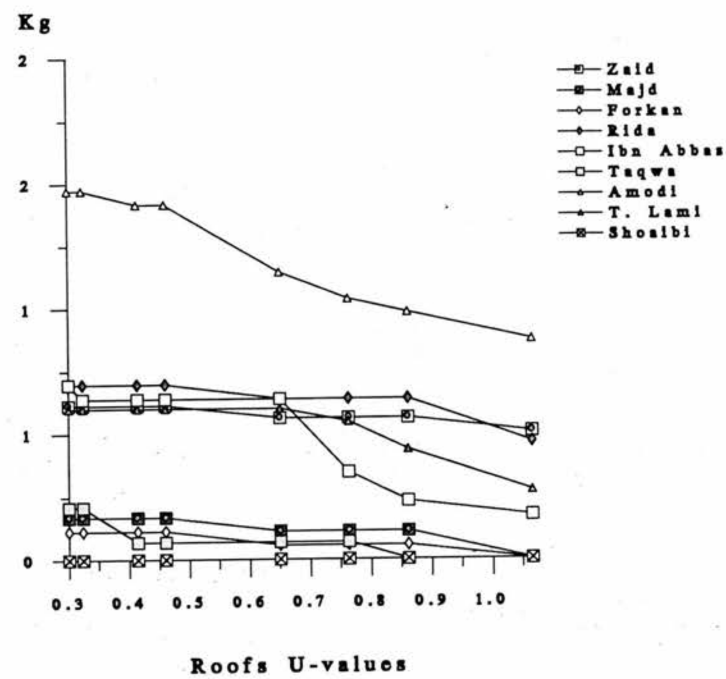


Figure 8.12 The figure show that there is a positive relationship between the roof U-values and the estimated savings in air conditioning energy, money, CO_2 and CFCs emissions.

Table 8.41 The different savings in air conditioning energy, money, CO_2 emission, CFCs emissions, and payback period by using various proposed building and insulation materials in existing roofs

1. Air conditioning energy, money and CO_2 emission savings (%)

Roof	U-value	Zaid	Majd	Forkan	Rida	Ibn Abbas	Taqwa	Amodi	T.Lami	Shoaibi
0	1.096	27.46	13.226	9.66	22.4	13.74	8.66	21.17	10.8	5.42
1	.892	31.13	14.995	10.96	25.39	15.58	9.82	24	12.2	6.14
2	.681	34.45	16.62	12.15	28.15	17.27	10.89	26.61	13.5	6.81
3	.444	37.79	18.362	13.42	31.1	19.08	11.96	29.22	14.9	7.52
4	.330	40.13	19.328	14.13	32.73	20.09	12.66	30.94	15.7	7.92
5	.794	32.67	15.736	11.5	26.65	16.35	10.31	25.19	12.8	6.44
6	.490	37.56	18.091	13.22	30.64	18.8	11.85	28.96	14.7	7.41
7	.354	39.74	19.137	13.99	32.41	19.89	12.45	30.64	15.6	7.84

2. CFCs emissions saving (%)

Roof	U-value	Zaid	Majd	Forkan	Rida	Ibn Abbas	Taqwa	Amodi	T.Lami	Shoaibi
0	1.096	21.4	0	0	14.82	5.08	0	19.5	5.31	0
1	.892	23.8	3.8	1.6	20.38	6.77	0	21.9	8.5	0
2	.681	23.8	3.8	1.6	20.38	18.64	1.6	25.6	11.7	0
3	.444	26.1	5.7	3.2	22.23	18.64	1.6	31.17	11.7	0
4	.330	26.1	5.7	3.2	22.23	20.33	5.08	32.9	11.7	0
5	.794	23.8	3.8	3.2	20.38	10.16	1.6	23.17	10.6	0
6	.490	26.1	5.7	3.2	22.23	18.64	1.6	31.17	11.7	0
7	.354	26.1	5.7	3.2	22.23	18.64	5.08	32.9	11.7	0

3. Payback period (Years)

Roof	Zaid	Majd	Forkan	Rida	Ibn Abbas	Taqwa	Amodi	T.Lami	Shoaibi
0	37	38	38	38	38	38	38	38	38
1	57	59	59	59	59	59	59	59	59
2	71	73	73	73	73	73	73	74	73
3	65	66	66	66	66	67	67	67	66
4	61	63	63	63	63	63	63	63	63
5	59	61	61	61	61	61	61	61	61
6	51	53	53	53	53	53	53	53	53
7	48	50	50	50	50	50	50	50	50

21.17% in Amodi mosque, 10.8% in T. Lami mosque and 5.42% in Shoaibi mosque of air conditioning energy, money and CO_2 emissions with saving in CFCs emissions of about 21.4% in Zaid, 14.82% in Rida, 5.08% in Ibn Abbas, 19.5% in Amodi and 5.31% in T. Lami mosque.

B. Cavity ceiling with cork board (C1)

When applying the cavity ceiling with cork board (C1) the air conditioning energy, money and the CO_2 emissions savings were found to be 31.13% in Zaid, 14.99% in Majd, 10.96% in Forkan, 25.39% in Rida, 15.58% in Ibn Abbas, 9.82% in Taqwa, 24% in Amodi, 12.2% in T. Lami and 6.14% in Shoaibi accompanied with an approximate saving in CFCs emissions of 23.8% in Zaid, 3.8% in Majd, 1.6% in Forkan, 20.38% in Rida, 6.77% in Ibn Abbas, 21.9% in Amodi and 8.5% in T. Lami mosque can be achieved.

C. Extruded polystyrene covered with cork board (C2, C3, C4)

In applying extruded polystyrene of various thickness covered with cork board (C2, C3, and C4) one can save about 34.35%, 37.79% and 40.13% in Zaid, 16.62%, 18.36% and 19.32% in Majd, 12.15%, 13.42% and 14.13% in Forkan, 28.15% 31.10% and 32.73% in Rida, 17.27%, 19.08% and 20.09% in Ibn Abbas, 10.89%, 11.96% and 12.66% in Taqwa, 26.61%, 29.22% and 30.94% in Amodi, 13.5%, 14.9%, 15.7% in T. Lami and 6.81%, 7.52% and 7.92% in Shoaibi mosque of the consumed air conditioning energy, money and the associated CO_2 emissions. The reductions of CFCs emissions were found to be about 23.8%, 26.1% and 26.1% in Zaid, 3.8% and 5.7% in Majd, 1.6% and 3.2% in Forkan, 20.38% and 22.38% in Rida, 18.64% and 20.33% in Ibn Abbas, 1.6% and 5.08% in Taqwa, 25.6%, 31.17% and 32.9% in Amodi, and 11.7% in T. Lami with no emission saving in Shoaibi mosque.

D. Extruded polystyrene covered with plaster board (C5, C6, C7)

As for adopting C5, C6, and C7 ceilings where extruded polystyrene of various thickness covered with plaster board are used, a possible air conditioning energy, money and CO_2 emissions savings of about 32.67%, 37.56% and 39.74% in Zaid, 15.73%, 18.09%, 19.13% in Majd, 11.50%, 13.22% and 13.99% in Forkan, 26.65%, 30.64% and 32.41% in Rida, 16.35%, 18.8%, 19.89% in Ibn Abbas, 10.31%, 11.85% and 12.45% in Taqwa, 25.19%, 28.96% and 30.64% in Amodi 12.8%, 14.7%, 15.6% in T. Lami and 6.44%, 7.41% and 7.84% in Shoaibi mosque can be obtained. As far as the CFCs emissions saving is concerned found, the savings were found to be about 23.8% and 26.1% in Zaid, 3.8%, 5.7% in Majd, 1.60%, 3.2% in Forkan, 20.38%, 22.23% in Rida, 10.16%, 18.64% in Ibn Abbas, 1.6% and 5.08% in Taqwa, 23.17%, 31.17% and 32.9% in Amodi and 10.6%, 11.7% in T. Lami with no CFCs emission saving in Shoaibi mosque. This result shows a good potential for savings in air conditioning energy, CO_2 emissions, and CFCs emissions by modifying the current U-values of existing roof with the use of eight ceiling types.

E. The cost effective analysis of the proposed roofs

Similarly, the results shows the various cost effectiveness of the different simulated roof type. Basically, it shows the relationship between cost of the roof per square metre, the savings per square metre and the overall pay back period for the different roof types. It can be seen that the different simulated roof types are also not cost effective, due to the fact that the predicted pay back periods are long in all mosques ; 38 years for C0, 59 years for C1, 73 years for R2, 67 years for C3, 63 years for C4, 61 years for C5, 53 years for C6 and 50 years for C7.

7.3.2.3.3 Combination of proposed walls and roofs and the potential savings in air conditioning energy, money, CO_2 emissions, and CFCs emissions in all mosque categories

Due to modification to existing walls and roof, the amounts of air conditioning energy, money, CO_2 emissions, and CFCs emissions savings by each building element separately shows a potential for saving air conditioning energy, money, CO_2 emissions and CFCs emissions. However, the amount of savings does not reflect the optimum savings that can be achieved by the improvement of existing building elements through the addition of building and insulation materials. Greater potential savings can be accomplished by using different combinations of modified walls and roofs by adding various building materials; a superior savings of 40.95% to 63% in Zaid, 20.66% to 31.94% in Majd, 12.96% to 19.73% in Forkan, 34.49% to 53.24% in Rida, 19.07% to 29.13% in Ibn Abbas, 11.52% to 17.51% in Taqwa, 30.35% to 46.53% in Amodi, 15.17% to 23.19% in T. Lami and 7.54% to 11.52% in Shoaibi mosque in air conditioning energy, money, CO_2 emissions, and up to 61% in Zaid, 26.75% in Majd, 8.11% in Forkan, 44.47% in Rida, 25.42% in Ibn Abbas, 10.16% in Taqwa, 47.5% in Amodi, 19.1% in T. Lami and 1.10% in Shoaibi in CFCs emissions.

A. Combination of C4 and C7 with all proposed walls

Table 8.42 summarises the maximum percentages of savings that are concluded from the calculation procedures for all nine mosques when using roof with ceiling no. 4 (C4) and no. 7 (C7) with respect to all modified walls (W0, W1, W2, W3, W4, W5, W6 and W7). As for using C4 with all modified walls savings in air conditioning energy consumption, money and CO_2 emissions are about 53.62% to 63.02% in Zaid, 26.76% to 31.94% in Majd, 17.43% to 19.73% in Forkan, 44.82% to 53.24% in Rida, 25.42% to 29.13% in Ibn Abbas, 15.52% to 17.51% in Taqwa, 40.12% to 46.52% in Amodi, 20.14% to 23.19% in T. Lami and 10.04% to 11.52% in Shoaibi. Savings in CFCs emissions were found to be about 50% to 61%, 21 to 26.75%, 3.2% to 8.11%, 37.06% to 44.47%, 23.72% to 25.42%, 5.08% to 10.16%, 39% to 47.5%, 15.9% to 19.1% and 0% to 1.10% respectively. While for using roof no. 7 with all modified walls savings in air conditioning energy consumption and CO_2 emissions are about 53.232% to 62.63% in Zaid, 26.57% to 31.75% in Majd, 17.29% to 19.59% in Forkan, 44.5% to 52.92% in Rida, 25.22% to 28.93% in Ibn Abbas, 15.31% to 17.3% in Taqwa, 39.82% to 46.22% in Amodi, 19.96% to 23.01% in T. Lami and 9.96% to 11.44% in Shoaibi. The CFCs savings were found

Table 8.42 Savings percentages in air conditioning energy, money and CO_2 emissions of various combinations of roofs type R4 and R7 and walls in nine mosques

1. Air conditioning energy, money and CO_2 emissions

	Zaid		Majd		Forkan		Rida		Ibn Abbas		Taqwa		Amodi		T. Lami		Shoaibi	
	R4	R7	R4	R7	R4	R7	R4	R7	R4	R7	R4	R7	R4	R7	R4	R7	R4	R7
W0	53.62	53.23	26.766	26.575	17.43	17.29	44.82	44.5	25.42	25.222	15.52	15.31	40.12	39.82	20.14	19.96	10.04	9.96
W1	59.22	58.83	29.851	29.66	18.8	18.66	49.83	49.51	27.63	27.432	16.7	16.49	43.93	43.63	21.96	21.78	10.92	10.84
W2	61.53	61.14	31.126	30.935	19.37	19.23	51.9	51.58	28.54	28.342	17.19	16.98	45.51	45.21	22.71	22.53	11.29	11.21
W3	63.02	62.63	31.948	31.757	19.73	19.59	53.24	52.92	29.13	28.932	17.51	17.3	46.52	46.22	23.19	23.01	11.52	11.44
W4	57.04	56.65	28.651	28.46	18.27	18.13	47.65	47.33	26.77	26.572	16.19	15.98	42.45	42.15	21.25	21.07	10.54	10.46
W5	60.68	60.29	30.659	30.468	19.16	19.02	51.15	50.83	28.21	28.012	17.02	16.81	44.93	44.63	22.43	22.25	11.15	11.07
W6	62.59	62.2	31.71	31.519	19.63	19.49	52.85	52.53	28.96	28.762	17.42	17.21	46.23	45.93	23.05	22.87	11.46	11.38
W7	57.25	56.86	28.778	28.587	18.32	18.18	48.07	47.75	26.85	26.65	16.29	16.08	42.60	42.30	21.32	21.14	10.61	10.53

2. CFCs emissions

	Zaid		Majd		Forkan		Rida		Ibn Abbas		Taqwa		Amodi		T. Lami		Shoaibi	
	R4	R7	R4	R7	R4	R7	R4	R7	R4	R7	R4	R7	R4	R7	R4	R7	R4	R7
W0	50.0	50.0	21.00	21.00	3.20	3.20	37.06	38.91	23.72	23.72	5.08	5.08	39.00	39.00	15.9	15.9	0.0	0.0
W1	57.0	57.1	24.84	24.84	6.40	6.40	42.61	42.61	23.72	23.72	5.08	5.08	45.10	45.10	17.0	17.0	0.0	0.0
W2	59.5	59.5	26.75	26.75	6.40	6.40	42.61	42.61	23.72	23.72	8.47	5.08	46.34	45.12	19.1	19.1	1.1	1.1
W3	61.0	61.0	26.75	26.75	8.11	8.11	44.47	44.47	25.42	25.42	10.16	8.47	47.50	47.50	19.1	19.1	1.1	1.1
W4	54.7	54.7	24.84	24.84	4.80	4.80	40.76	40.76	23.72	23.72	5.08	5.08	41.40	41.40	15.9	15.9	0.0	0.0
W5	59.5	59.5	26.75	24.84	6.40	6.40	42.61	42.61	23.72	23.72	5.08	5.08	45.12	45.12	18.0	18.0	1.1	1.1
W6	59.5	59.5	26.75	26.75	8.11	8.11	44.47	42.61	25.42	25.42	8.47	8.47	47.50	47.50	19.1	19.1	1.1	1.1
W7	54.7	54.7	24.84	24.84	4.80	4.80	40.76	40.76	23.72	23.72	5.08	5.08	41.40	41.40	15.9	15.9	0.0	0.0

to be about 50% to 61%, 21% to 26.75%, 3.2% to 8.11%, 38.91% to 44.47%, 5.08% to 8.47%, 39% to 47.5%, 15.9% to 19.1% and 0% to 1.10% respectively.

B. Various combinations with higher savings

Table 8.43 indicates those combinations that give higher savings in air conditioning energy, money and CO_2 emissions; 60.25% to 63% in Zaid, 30.46% to 31.94% in Majd, 18.8% to 19.73% in Forkan, 50.83% to 53.2% in Rida, 27.85% to 29.13% in Ibn Abbas, 16.7% to 17.51% in Taqwa, 44.51% to 46.52% in Amodi, 22.18% to 23.19% in T. Lami and 11.01% to 11.52% in Shoaibi with CFCs emissions savings of 59.5% to 61% in Zaid, 26.75 in Majd, 6.4% to 8.11% in Forkan, 42.61% to 44.47% in Rida, 23.72% to 25.42% in Ibn Abbas, 5.08% to 10.16% in Taqwa, 45.12% to 47.5% in Amodi, 18% to 19.1% in T. Lami and 1.10% in Shoaibi mosque. A significant savings in air conditioning energy, money, CO_2 emissions, and CFCs emissions can be obtained by using a combination of the roof using ceiling no. 4 and the modified walls W3, significant savings of 63% in Zaid, 31.94% in Majd, 19.73% in Forkan, 53.20% in Rida, 29.13% in Ibn Abbas, 17.51% in Taqwa, 46.52% in Amodi, 23.19% in T. Lami and 11.52% in Shoaibi mosque in air conditioning energy, money, CO_2 emissions and 61%, 26.75%, 8.1%, 44.47%, 25.42%, 10.16%, 47.5%, 19.1% and 1.10% respectively in CFCs emissions can be achieved.

C. The cost effective analysis of the proposed combinations

The figure indicates that the cost effectiveness of the different combination

Table 8.43 Savings percentages in air conditioning energy, money, CO_2 emission, CFCs emissions and the payback period of various combinations of walls and roofs

1. Air conditioning energy, money and CO_2 emission savings (%)

Combin.	Roof	Wall	Zaid	Majd	Forkan	Rida	Ibn Abbas	Taqwa	Amodi	T. Lami	Shoaibi
C1	4	3	63	31.94	19.73	53.2	29.13	17.51	46.52	23.19	11.52
C2	4	6	62.5	31.71	19.63	52.8	28.96	17.42	46.23	23.05	11.46
C3	7	3	62.6	31.75	19.59	52.9	28.93	17.3	46.22	23.04	11.44
C4	7	6	62.2	31.52	19.49	52.5	28.76	17.21	45.93	22.9	11.38
C5	4	2	61.5	31.12	19.37	51.9	28.54	17.19	45.51	22.71	11.29
C6	7	2	61.1	30.93	19.23	51.5	28.34	16.98	45.21	22.55	11.21
C7	3	3	60.6	30.98	19.02	51.6	28.13	16.81	44.8	22.4	11.12
C8	4	5	60.6	30.66	19.16	51.15	28.21	17.02	44.93	22.44	11.15
C9	6	3	60.45	30.71	18.82	51.15	27.85	16.7	44.54	22.18	11.01
C10	7	5	60.29	30.46	19.02	50.83	28.01	16.81	44.63	22.28	11.07
C11	3	6	60.25	30.74	18.92	51.2	27.96	16.72	44.51	22.26	11.06

2. CFCs emissions saving (%)

Combin.	Roof	Wall	Zaid	Majd	Forkan	Rida	Ibn Abbas	Taqwa	Amodi	T. Lami	Shoaibi
C1	4	3	61	26.75	8.11	44.47	25.42	10.16	47.5	19.1	1.1
C2	4	6	59.5	26.75	8.11	44.47	25.42	8.47	47.5	19.1	1.1
C3	7	3	61	26.75	8.11	44.47	25.42	8.47	47.5	19.1	1.1
C4	7	6	59.5	26.75	8.11	42.61	25.42	8.47	47.5	19.1	1.1
C5	4	2	59.5	26.75	6.4	42.61	23.72	8.47	46.34	19.1	1.1
C6	7	2	59.5	26.75	6.4	42.61	23.72	5.08	45.12	19.1	1.1
C7	3	3	59.5	26.75	6.4	42.61	23.72	5.08	45.12	18	1.1
C8	4	5	59.5	26.75	6.4	42.61	23.72	5.08	45.12	18	1.1
C9	6	3	59.5	26.75	6.4	42.61	23.72	5.08	45.12	18	1.1
C10	7	5	59.5	24.84	6.4	42.61	23.72	5.08	45.12	18	1.1
C11	3	6	59.5	26.75	6.4	42.61	23.72	5.08	45.12	18	1.1

3. Payback period (Years)

Combin.	Roof	Wall	Zaid	Majd	Forkan	Rida	Ibn Abbas	Taqwa	Amodi	T. Lami	Shoaibi
C1	4	3	63	66	66	66	65	66	66	66	65
C2	4	6	70	73	73	73	73	73	73	73	72
C3	7	3	54	57	57	57	57	57	57	57	56
C4	7	6	61	64	64	64	64	64	64	64	63
C5	4	2	65	67	70	67	67	67	68	67	67
C6	7	2	56	58	58	58	58	58	58	58	57
C7	3	3	70	68	68	68	68	68	68	68	67
C8	4	5	72	75	75	75	75	75	75	75	74
C9	6	3	57	59	59	59	59	59	59	59	58
C10	7	5	63	66	66	66	65	66	66	66	65
C11	3	6	78	75	75	75	75	75	76	76	75

are not significant due to their high purchasing costs compared to their savings. The payback periods of various combinations in all mosques were as follows; 63 to 66 years for C1, 70 to 73 years for C2, 54 to 57 years for C3, 61 to 64 for C4, 65 to 70 years for C5, 56 to 58 years for C6, 67 to 70 years for C7, 72 to 75 years for C8, 57 to 59 years for C9 and 63 to 66 years for C10.

In conclusion, it was found that the modification of existing roof and walls of air conditioned mosque by using the proposed building and insulation materials has a very low cost effectiveness but they contribute substantially to energy, CO_2 and CFCs emissions.

8.3.3 Notes on the proposed passive cooling strategy and improvement measures performances

From the above discussion, two important issues are found:

1. The percentages of savings tend to be low in mosques with high air conditioning energy consumption.
2. The cost effectiveness of the proposed improvement measures of complete shading is found to quite high (7 to 15 years) while for the various building and insulation materials for existing walls and roofs is found to be very low indeed. This is due to the following factors:
    a. Energy is very cheap in the Kingdom. (1 Kwh = £ 0.008)
    b. Labour cost is considered high.
    c. Building materials tend to be high.

Unfortunately, this scenario can not be changed in short time due to the fact that:

a. Energy is abundant in Saudi Arabia.

b. Lack of local labours (heavily dependent on foreign labours).

c. Lack of local building materials. Currently, most building materials are imported from abroad. Few are produced locally with the use of imported raw materials and foreign skilled labours.

Under these circumstances it seems obvious to focus on the management scenario of existing buildings by:

a. Adopting the proposed passive cooling strategy where up to 80s% of savings in air conditioning energy, money and CO_2 and CFCs emissions can be achieved at no extra cost.

b. Setting a target of air conditioning energy use per cubic metre for mosque experiencing higher air conditioning energy consumption with lower level of energy consumption practised in low energy mosque.

Based on the analysis of mosques management in each category, the differences in air conditioning energy consumption between the mosques having same sizes are found to be primarily related to:

1. The degree of coolness.

2. The types and numbers of air conditioning systems used.

Therefore, the minimum requirement of cooling in each category is found to be the one which experiencing 25°C as indoor temperature and consuming 10.14 to 11.95

Kwh per cubic metre. This figure has been applied to those mosques experiencing high air conditioning energy consumption levels and the corresponding savings are presented in Table 8.44. The results reveal that savings in air conditioning energy, money and CO emission levels ranging from 50% to 74% can be achieved with no cost at all. The only cost will be the change in cooling level (from 23°C and 24°C to 25°C).

Table 8.44 Savings in air conditioning energy, money and CO_2 emission levels by setting a target of air conditioning energy consumption per cubic metre in mosque experiencing higher air conditioning energy consumption level.

Mosque type	AC. energy currently used (Kwh)	AC. energy estimated for use (Kwh)	AC. energy saved (Kwh)	CO_2 emisn. saved (Kg)	Money saved (SRi)	% of CO_2, money and ac. en. saved
I-A	15231	0	0	0	0	0
I-B	47420	18881.57	28538.42	1683.76	1426.92	60.18
I-C	72675	19743	52931.48	3122.95	2646.57	72.83
II-A	46123	0	0	0	0	0
II-B	90687	45027.6	45659.4	2693.9	2282.97	50.34
II-C	105908	28763	77144.35	4551.51	3857.21	72.84
III-A	64894	0	0	0	0	0
III-B	119074	53629.8	65444.17	3861.2	3272.2	54.96
III-C	467314	118389.58	348924.4	20586.5	17446.22	74.66

8.3.4 The measures potential savings tables

The saving figures of the proposed improvement measures in all nine mosques has been used to produce a set of tables which can be useful in estimating the potential savings in air conditioning energy, money, CO_2 emissions and CFCs emissions for any mosque. These tables are classified into two groups:

1. Group one; related to air conditioning energy, money and CO emissions saving estimation.
2. Group two; related to the CFCs emission saving estimation.

In using these tables, the first step is to define the category of the studied mosque by knowing the volume of the mosque and the average air conditioning energy consumption for each cubic metre.

8.3.4.1 Tables for air conditioning, money and CO_2 emissions estimations

These tables (Group1) are used to calculate the air conditioning energy, money and CO_2 emission savings of any measure selected under a defined mosque category. The following items have to be determined:

1. The volume of the space which will be ventilated (For night ventilation).
2. The total area of windows (For complete shading existing windows).
3. The areas of walls and roof (For using building and insulation materials in existing walls and roof).

8.3.4.2 Tables for CFCs emission estimations

These tables (Group 2) are used in calculating the potential saving in CFCs emissions through determining the number of air conditioning units saved on monthly basis. This can be achieved by calculating the reduction percentage of air conditioning energy achieved. The following items should be defined;

1. The monthly air conditioning energy consumption level.
2. The numbers of air conditioners used each month.

GROUP ONE: Tables used for the estimation of air conditioning energy, money and CO_2 emission savings

A. Night ventilation

Mosque volume	Average air cond. energy consump. Kwh/ 1m^3	Cost (1m^2) in SRi	0	Mosque volume	Average air cond. energy consump. Kwh/ 1m^3	Cost (1m^2) in SRi	0	Mosque volume	Average air cond. energy consump. Kwh/ 1m^3	Cost (1m^2) in SRi	0
up to 2000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^3	0.436844	**2001 to 5000 m^3**	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^3	0.436849	**Over 5001m^3**	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^3	0.436843
		CO_2 saved /m^3	0.025774			CO_2 saved /m^3	0.025774			CO_2 saved /m^3	0.025774
		Money saved /m^3	0.021842			Money saved /m^3	0.021842			Money saved /m^3	0.021842
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	0.436824		19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	0.436843		19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	0.436838
		CO_2 saved /m^3	0.025773			CO_2 saved /m^3	0.025774			CO_2 saved /m^3	0.025773
		Money saved /m^3	0.021841			Money saved /m^3	0.021842			Money saved /m^3	0.021842
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^3	0.432198		33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^3	0.436851		33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^3	0.436838
		CO_2 saved /m^3	0.0255			CO_2 saved /m^3	0.025774			CO_2 saved /m^3	0.025773
		Money saved /m^3	0.02161			Money saved /m^3	0.021843			Money saved /m^3	0.021842

B. Complete Shading of Existing Windows

Mosque volume	Average air cond. energy consump. Kwh/ 1m^3	Cost (1m^2) in SRi	65	Mosque volume	Average air cond. energy consump. Kwh/ 1m^3	Cost (1m^2) in SRi	65	Mosque volume	Average air cond. energy consump. Kwh/1m^3	Cost (1m^2) in SRi	65
up to 2000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	173.59	**2001 to 5000 m^3**	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	170.98	**Over 5001m^3**	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	72.94
		CO_2 saved /m^2	10.229			CO_2 saved /m^2	10.083			CO_2 saved /m^2	4.303
		Money saved /m^2	8.670			Money saved /m^2	8.533			Money saved /m^2	3.647
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	161.45		19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	158.11		19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	157.64
		CO_2 saved /m^2	9.518			CO_2 saved /m^2	9.318			CO_2 saved /m^2	9.299
		Money saved /m^2	8.059			Money saved /m^2	7.895			Money saved /m^2	7.877
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	155.489		33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	180.38		33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	182.16
		CO_2 saved /m^2	9.172			CO_2 saved /m^2	10.631			CO_2 saved /m^2	10.74
		Money saved /m^2	7.768			Money saved /m^2	9.008			Money saved /m^2	9.099

C. Insulation of Existing Walls and Roofs

1. Walls

			Insulation of existing walls							
			W0	W1	W2	W3	W4	W5	W6	W7
Mosque volume	Average air cond. engy. consump. Kwh/ $1m^3$	Cost ($1m^2$) in SRi	25	52	52	52	67	67	67	25
up to 2000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	8.567042	12.11529	13.58229	14.53021	10.73358	13.04592	14.25704	10.87075
		CO_2 saved /m^2	0.505455	0.714802	0.801355	0.857282	0.633281	0.769709	0.841165	0.641374
		Money saved /m^2	0.428352	0.605765	0.679115	0.726511	0.536679	0.652296	0.712852	0.543538
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	8.578903	12.13709	13.60847	14.55677	10.75321	13.06975	14.28181	10.89003
		CO_2 saved /m^2	0.506155	0.716088	0.8029	0.858849	0.634439	0.771115	0.842627	0.642512
		Money saved /m^2	0.428945	0.606855	0.680424	0.727839	0.537661	0.653488	0.714091	0.544502
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	8.609176	12.17875	13.65477	14.60663	10.79004	13.11452	14.33104	10.92806
		CO_2 saved /m^2	0.507941	0.718546	0.805631	0.861791	0.636612	0.773757	0.845531	0.644756
		Money saved /m^2	0.430459	0.608938	0.682739	0.730332	0.539502	0.655726	0.716552	0.546403

			Insulation of existing walls							
			W0	W1	W2	W3	W4	W5	W6	W7
Mosque volume	Average air cond. engy. consump. Kwh/ $1m^3$	Cost ($1m^2$) in SRi	25	52	52	52	67	67	67	25
2000 to 5000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	8.661025	12.25124	13.73578	14.69352	10.69071	13.19253	14.41651	10.99304
		CO_2 saved /m^2	0.511	0.722823	0.810411	0.866918	0.630752	0.778359	0.850574	0.648589
		Money saved /m^2	0.433051	0.612562	0.686789	0.734676	0.534536	0.659627	0.720826	0.549652
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	8.662868	12.25379	13.7386	14.69656	10.85648	13.19527	14.41951	10.99527
		CO_2 saved /m^2	0.511109	0.722974	0.810577	0.867097	0.640532	0.778521	0.850751	0.648721
		Money saved /m^2	0.433143	0.61269	0.68693	0.734828	0.542824	0.659764	0.720976	0.549764
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	8.713506	12.32368	13.81635	14.78023	10.75296	13.2704	14.50207	11.05786
		CO_2 saved /m^2	0.514097	0.727097	0.815165	0.872034	0.634425	0.782954	0.855622	0.652414
		Money saved /m^2	0.435675	0.616184	0.690818	0.739012	0.537648	0.66352	0.725104	0.552893

			Insulation of existing walls							
			W0	W1	W2	W3	W4	W5	W6	W7
Mosque volume	Average air cond. engy. consump. Kwh/ $1m^3$	Cost ($1m^2$) in SRi	25	52	52	52	67	67	67	25
Over 5000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	8.55208	12.09981	13.5669	14.51205	10.72022	13.02966	14.23783	10.8575
		CO_2 saved /m^2	0.504573	0.713889	0.800447	0.856211	0.632493	0.76875	0.840032	0.640593
		Money saved /m^2	0.427604	0.604991	0.678345	0.725603	0.536011	0.651483	0.711892	0.542875
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	8.606014	12.17425	13.64973	14.60124	10.78606	13.10968	14.32576	10.92401
		CO_2 saved /m^2	0.507755	0.718281	0.805334	0.861473	0.636378	0.773471	0.84522	0.644517
		Money saved /m^2	0.430301	0.608713	0.682487	0.730062	0.539303	0.655484	0.716288	0.546201
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	8.878304	12.55321	14.0725	15.05518	10.95134	13.51732	14.77277	11.26349
		CO_2 saved /m^2	0.52382	0.740639	0.830278	0.888256	0.646129	0.797522	0.871593	0.664546
		Money saved /m^2	0.443915	0.627661	0.703625	0.752759	0.547567	0.675866	0.738639	0.563175

2. Roofs

			Insulation of existing roof							
			R0	R1	R2	R3	R4	R5	R6	R7
Mosque volume	Average air cond. engy. consump. Kwh/ $1m^3$	Cost ($1m^2$) in SRi	40	70	97	97	97	76	76	76
up to 2000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	20.917	23.7137	26.28445	28.8699	30.5665	24.88635	28.61075	30.2647
		CO_2 saved /m^2	1.234103	1.399108	1.550783	1.703324	1.803424	1.468295	1.688034	1.785617
		Money saved /m^2	1.04585	1.185685	1.314223	1.443495	1.528325	1.244318	1.430538	1.513235
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	20.907	23.70253	26.27207	29.02456	30.5521	24.87462	28.59725	30.25045
		CO_2 saved /m^2	1.233513	1.398449	1.550052	1.712449	1.802574	1.467603	1.687238	1.784777
		Money saved /m^2	1.04535	1.185127	1.313604	1.451228	1.527605	1.243731	1.429863	1.512523
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	20.913	23.71036	26.28074	29.03417	30.5622	24.88283	28.60667	30.26042
		CO_2 saved /m^2	1.233867	1.398911	1.550564	1.713016	1.80317	1.468087	1.687794	1.785365
		Money saved /m^2	1.04565	1.185518	1.314037	1.451709	1.52811	1.244142	1.430334	1.513021

			Insulation of existing roof							
			R0	R1	R2	R3	R4	R5	R6	R7
Mosque volume	Average air cond. engy. consump. Kwh/ $1m^3$	Cost ($1m^2$) in SRi	40	70	97	97	97	76	76	76
2000 to 5000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	20.917	23.71377	26.28441	29.03826	30.5666	24.88644	28.61073	30.26478
		CO_2 saved /m^2	1.234103	1.399112	1.55078	1.713257	1.803429	1.4683	1.688033	1.785622
		Money saved /m^2	1.04585	1.185689	1.314221	1.451913	1.52833	1.244322	1.430537	1.513239
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	20.893	23.68692	26.25477	29.00551	30.53197	24.85825	28.57841	30.23054
		CO_2 saved /m^2	1.232687	1.397528	1.549031	1.711325	1.801386	1.466637	1.686126	1.783602
		Money saved /m^2	1.04465	1.184346	1.312739	1.450276	1.526599	1.242913	1.428921	1.511527
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	20.916	23.71276	26.28337	28.86879	30.56538	24.88542	28.60957	30.05308
		CO_2 saved /m^2	1.234044	1.399053	1.550719	1.703259	1.803357	1.46824	1.687965	1.773132
		Money saved /m^2	1.0458	1.185638	1.314169	1.44344	1.528269	1.244271	1.430479	1.502654

			Insulation of existing roof							
			R0	R1	R2	R3	R4	R5	R6	R7
Mosque volume	Average air cond. engy. consump. Kwh/ $1m^3$	Cost ($1m^2$) in SRi	40	70	97	97	97	76	76	76
Over 5000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	20.917	23.714	26.28478	28.87017	30.56682	24.88661	28.61096	30.26499
		CO_2 saved /m^2	1.234103	1.399126	1.550802	1.70334	1.803442	1.46831	1.688047	1.785634
		Money saved /m^2	1.04585	1.1857	1.314239	1.443509	1.528341	1.244331	1.430548	1.51325
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	20.913	23.70945	26.27974	29.03307	30.56101	24.88189	28.60559	30.25928
		CO_2 saved /m^2	1.233867	1.398858	1.550505	1.712951	1.8031	1.468032	1.68773	1.785298
		Money saved /m^2	1.04565	1.185473	1.313987	1.451654	1.528051	1.244095	1.43028	1.512964
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	20.915	23.71255	26.28315	29.03683	30.56499	24.88514	28.60933	30.26317
		CO_2 saved /m^2	1.233985	1.39904	1.550706	1.713173	1.803334	1.468223	1.68795	1.785527
		Money saved /m^2	1.04575	1.185628	1.314158	1.451842	1.52825	1.244257	1.430467	1.513159

3. Combinations of Walls and Roofs

			Insulation of existing walls and roof		
			C1	C3	C4
Mosque volume	Average air cond. engy. consump. Kwh/ $1m^3$	Cost ($1m^2$) in SRi	149	164	128
Up to 2000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	45.09671	44.82354	44.79491
		CO_2 saved /m^2	2.660706	2.644589	2.6429
		Money saved /m^2	2.254836	2.241177	2.239746
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	45.10887	44.83391	44.80722
		CO_2 saved /m^2	2.661423	2.645201	2.643626
		Money saved /m^2	2.255444	2.241696	2.240361
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	45.16883	44.89324	44.86705
		CO_2 saved /m^2	2.664961	2.648701	2.647156
		Money saved /m^2	2.258442	2.244662	2.243353

			Insulation of existing walls and roof		
			C1	C3	C4
Mosque volume	Average air cond. engy. consump. Kwh/ $1m^3$	Cost ($1m^2$) in SRi	149	164	128
2000 to 5000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	45.26012	44.98311	44.9583
		CO_2 saved /m^2	2.670347	2.654003	2.65254
		Money saved /m^2	2.263006	2.249156	2.247915
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	45.22854	44.95149	44.9271
		CO_2 saved /m^2	2.668484	2.652138	2.650699
		Money saved /m^2	2.261427	2.247575	2.246355
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	45.34561	45.06744	44.83331
		CO_2 saved /m^2	2.675391	2.658979	2.645165
		Money saved /m^2	2.267281	2.253372	2.241666

			Insulation of existing walls and roof		
			C1	C3	C4
Mosque volume	Average air cond. engy. consump. Kwh/ $1m^3$	Cost ($1m^2$) in SRi	149	164	128
Over 5000 m^3	1.69 to 16.77 Kwh (0.1 to 0.99 Kg of CO_2)	AC. energy saved/m^2	45.07887	44.80465	44.77704
		CO_2 saved /m^2	2.659653	2.643474	2.641845
		Money saved /m^2	2.253944	2.240233	2.238852
	19.94 to 33.72 Kwh (1 to 1.99 Kg of CO_2)	AC. energy saved/m^2	45.16225	44.88677	44.86053
		CO_2 saved /m^2	2.664573	2.648319	2.646771
		Money saved /m^2	2.258113	2.244339	2.243027
	33.89 Kwh and more (2 Kg of CO_2 and more)	AC. energy saved/m^2	45.62017	45.33776	45.31835
		CO_2 saved /m^2	2.69159	2.674928	2.673783
		Money saved /m^2	2.281009	2.266888	2.265918

GROUP TWO: Tables used for the estimation of CFCs savings

Small District Mosque: I-A

Months		N Vent $/m^3$	shad. $/m^2$	w0 $/m^2$	w1 $/m^2$	w2 $/m^2$	w3 $/m^2$	w4 $/m^2$	w5 $/m^2$	w6 $/m^2$	w7 $/m^2$
February		0.13629	16.593	0.608083	0.851583	0.951833	1.020625	0.753958	0.916375	1.003625	0.757334
March		0.1309	16.995	0.686417	0.964458	1.079083	1.156125	0.854083	1.038083	1.136042	0.860275
April		0.016427	16.028	0.7575	1.069583	1.1985	1.282625	0.9475	1.151583	1.258958	0.958358
May		0	15.262	0.792375	1.121833	1.258083	1.345542	0.993958	1.208083	1.319917	1.007591
June		0	16.028	0.881292	1.249625	1.402083	1.499	1.107292	1.345833	1.469958	1.123917
July		0	17.724	0.971292	1.377083	1.545042	1.651875	1.22025	1.483125	1.619917	1.238452
August		0	14.952	0.893708	1.270167	1.426125	1.523875	1.125708	1.368208	1.493583	1.144803
September		0	15.043	0.857208	1.217	1.366	1.46	1.0785	1.310833	1.431333	1.095869
October		0	15.335	0.797375	1.129583	1.267083	1.354917	1.000917	1.2165	1.328958	1.015178
November		0.016427	15.517	0.733	1.035792	1.160958	1.242208	0.917625	1.115292	1.219042	0.928733
December		0.136804	14.132	0.588875	0.828792	0.927792	0.993667	0.734042	0.892167	0.976	0.740412
Annual		0.436844	173.59	8.567042	12.11529	13.58229	14.53021	10.73358	13.04592	14.25704	10.87075

Months	r0 $/m^2$	r1 $/m^2$	r2 $/m^2$	r3 $/m^2$	r4 $/m^2$	r5 $/m^2$	r6 $/m^2$	r7 $/m^2$	r4w3 $/m^2$	r4w6 $/m^2$	r7w3 $/m^2$
February	1.363	1.5506	1.7186	1.88275	1.99845	1.6269	1.87055	1.9786	3.019075	3.002075	2.999225
March	1.77965	2.0231	2.2423	2.4579	2.6075	2.12275	2.44065	2.5816	3.763625	3.743542	3.737725
April	2.13865	2.428	2.69115	2.9528	3.1295	2.54785	2.92925	3.0985	4.412125	4.388458	4.381125
May	2.0529	2.3273	2.5796	2.8334	2.99985	2.4424	2.8079	2.97025	4.345392	4.319767	4.315792
June	2.3077	2.61495	2.89845	3.18475	3.3707	2.74435	3.155	3.33745	4.8697	4.840658	4.83645
July	2.68585	3.0447	3.37475	3.707	3.92455	3.19525	3.67345	3.8858	5.576425	5.544467	5.537675
August	2.29175	2.59425	2.8756	3.162	3.34415	2.72285	3.1302	3.3112	4.868025	4.837733	4.835075
September	2.09435	2.37075	2.62785	2.8896	3.05605	2.48825	2.8605	3.02595	4.51605	4.487383	4.48595
October	1.75365	1.9852	2.20045	2.41955	2.559	2.08355	2.3953	2.5338	3.913917	3.887958	3.888717
November	1.43405	1.62375	1.7998	1.9787	2.09305	1.7042	1.95915	2.07245	3.335258	3.312092	3.314658
December	1.0156	1.15125	1.27605	1.4017	1.48395	1.2082	1.389	1.4693	2.477617	2.45995	2.462967
Annual	20.917	23.7137	26.28445	28.8699	30.5665	24.88635	28.61075	30.2647	45.09671	44.82354	44.79491

Small District Mosque: I-B

Months		N Vent /m^3	shad. /m^2	w0 /m^2	w1 /m^2	w2 /m^2	w3 /m^2	w4 /m^2	w5 /m^2	w6 /m^2	w7 /m^2
February		0.136283	15.718	0.603298	0.845101	0.944657	1.012864	0.748228	0.909425	0.995927	0.751448
March		0.130893	15.408	0.677969	0.952959	1.066354	1.142414	0.843923	1.025734	1.122451	0.850021
April		0.016426	13.493	0.743518	1.050569	1.17747	1.259899	0.9307	1.131201	1.236449	0.941544
May		0	14.278	0.798755	1.131201	1.268731	1.356818	1.00229	1.218211	1.33089	1.015902
June		0	15.171	0.892324	1.265562	1.420065	1.518136	1.121453	1.363043	1.488643	1.13807
July		0	16.247	0.976942	1.38563	1.554808	1.66217	1.227851	1.492362	1.629866	1.246082
August		0	13.110	0.891497	1.267785	1.423725	1.521092	1.12363	1.365686	1.490659	1.142814
September		0	13.457	0.855329	1.215047	1.364055	1.457706	1.076809	1.30878	1.428878	1.094227
October		0	14.642	0.801868	1.13638	1.274811	1.363097	1.006927	1.223846	1.336844	1.021194
November		0.016426	15.390	0.739772	1.045621	1.17205	1.253996	0.926339	1.1259	1.230561	0.937405
December		0.136796	14.442	0.597655	0.841234	0.941741	1.008578	0.745054	0.905564	0.990646	0.751322
Annual		0.436824	161.452	8.578903	12.13709	13.60847	14.55677	10.75321	13.06975	14.28181	10.89003

Months	r0 /m^2	r1 /m^2	r2 /m^2	r3 /m^2	r4 /m^2	r5 /m^2	r6 /m^2	r7 /m^2	r4w3 /m^2	r4w6 /m^2	r7w3 /m^2
February	1.362679	1.550273	1.718202	1.895986	1.998007	1.626538	1.87015	1.978146	3.010871	2.993934	2.99101
March	1.779153	2.022553	2.241679	2.474257	2.606762	2.122164	2.439953	2.580887	3.749175	3.729213	3.723301
April	2.137837	2.427107	2.69014	2.970569	3.128325	2.546876	2.928152	3.097353	4.388224	4.364775	4.357252
May	2.051887	2.326193	2.578372	2.848528	2.99842	2.441228	2.806569	2.968818	4.355238	4.329311	4.325636
June	2.306513	2.613601	2.896968	3.201026	3.368943	2.74294	3.15339	3.335717	4.887079	4.857586	4.853853
July	2.684539	3.043202	3.373117	3.726633	3.922643	3.19371	3.671657	3.88392	5.584813	5.552509	5.54609
August	2.290394	2.592727	2.873895	3.176612	3.342167	2.721226	3.128333	3.309267	4.863259	4.832825	4.830359
September	2.093084	2.369371	2.626317	2.902956	3.054248	2.486799	2.858836	3.024182	4.511954	4.483126	4.481889
October	1.752604	1.984017	2.199172	2.43079	2.557503	2.082342	2.393872	2.532325	3.9206	3.894346	3.895422
November	1.433221	1.622811	1.798786	1.988091	2.091872	1.703209	1.958032	2.071269	3.345868	3.322433	3.325266
December	1.015087	1.150679	1.275424	1.409106	1.483209	1.20759	1.388308	1.468568	2.491787	2.473855	2.477147
Annual	20.907	23.70253	26.27207	29.02456	30.5521	24.87462	28.59725	30.25045	45.10887	44.83391	44.80722

Small District Mosque: I-C

Months		N Vent /m^3	shad. /m^2	w0 /m^2	w1 /m^2	w2 /m^2	w3 /m^2	w4 /m^2	w5 /m^2	w6 /m^2	w7 /m^2
February		0.134839	15.189	0.632652	0.885878	0.990143	1.06172	0.784337	0.953297	1.04405	0.787565
March		0.129507	15.025	0.687276	0.965878	1.080753	1.157885	0.855341	1.039606	1.137706	0.861541
April		0.016252	13.457	0.730573	1.032545	1.157384	1.238315	0.914767	1.111828	1.215197	0.925729
May		0	13.585	0.781111	1.106631	1.241326	1.327384	0.980538	1.191792	1.3019	0.994317
June		0	14.332	0.868853	1.232867	1.383584	1.478961	1.092509	1.327885	1.450072	1.109314
July		0	15.554	0.950466	1.348746	1.513656	1.617993	1.195233	1.452688	1.58638	1.213643
August		0	12.837	0.87957	1.251147	1.405125	1.501147	1.108889	1.347778	1.471004	1.128229
September		0	13.147	0.854839	1.214337	1.363262	1.456846	1.076201	1.308029	1.428065	1.093734
October		0	14.040	0.81871	1.159749	1.30086	1.391111	1.027599	1.248996	1.364444	1.041936
November		0.016252	14.642	0.773871	1.093011	1.224875	1.310753	0.96828	1.176846	1.286487	0.97936
December		0.135347	13.585	0.631398	0.888136	0.994014	1.064767	0.786559	0.956022	1.045986	0.792843
Annual		0.432198	155.489	8.609176	12.17875	13.65477	14.60663	10.79004	13.11452	14.33104	10.92806

Months	r0 /m^2	r1 /m^2	r2 /m^2	r3 /m^2	r4 /m^2	r5 /m^2	r6 /m^2	r7 /m^2	r4w3 /m^2	r4w6 /m^2	r7w3 /m^2
February	1.362887	1.550506	1.718452	1.89628	1.998214	1.626786	1.870417	1.978571	3.059935	3.042264	3.040292
March	1.779494	2.022946	2.242083	2.474732	2.607143	2.12256	2.440417	2.58125	3.765028	3.744849	3.739135
April	2.138393	2.427708	2.690804	2.97131	3.129167	2.54753	2.928899	3.098214	4.367482	4.344364	4.33653
May	2.05256	2.326935	2.579196	2.849435	2.999405	2.442024	2.80747	2.969643	4.326788	4.301304	4.297026
June	2.307321	2.614494	2.897976	3.202143	3.370238	2.743899	3.154464	3.336905	4.849199	4.82031	4.815865
July	2.685417	3.044196	3.374226	3.727857	3.92381	3.194762	3.672857	3.885119	5.541802	5.510189	5.503112
August	2.29131	2.59375	2.87503	3.177857	3.343452	2.722292	3.129554	3.310714	4.844599	4.814456	4.811861
September	2.093929	2.370298	2.627351	2.904107	3.055357	2.487768	2.85997	3.025298	4.512203	4.483422	4.482143
October	1.753304	1.984792	2.20003	2.431756	2.558631	2.083155	2.394821	2.533333	3.949742	3.923075	3.924444
November	1.43378	1.623423	1.799464	1.988869	2.09256	1.703869	1.95878	2.072024	3.403312	3.379047	3.382776
December	1.015417	1.151042	1.275833	1.409583	1.483631	1.207976	1.38875	1.469048	2.548398	2.529617	2.533815
Annual	20.91399	23.71036	26.28074	29.03417	30.5622	24.88283	28.60667	30.26042	45.16883	44.89324	44.86705

Large District Mosque: II-A

Months		N Vent /m^3	shad. /m^2	w0 /m^2	w1 /m^2	w2 /m^2	w3 /m^2	w4 /m^2	w5 /m^2	w6 /m^2	w7 /m^2
February		0.136289	18.070	0.607329	0.850699	0.950885	1.019565	0.737904	0.915435	1.002531	0.756537
March		0.130899	16.885	0.687733	0.966522	1.081475	1.158665	0.840093	1.040326	1.138447	0.86217
April		0.016427	14.040	0.760202	1.073758	1.203323	1.287671	0.936149	1.156134	1.263804	0.962213
May		0	13.858	0.807096	1.142795	1.281661	1.370699	0.997826	1.230683	1.344565	1.026346
June		0	14.350	0.900404	1.276786	1.432578	1.531584	1.115823	1.375124	1.501894	1.148211
July		0	15.554	0.988975	1.40236	1.573463	1.682205	1.225528	1.510357	1.649596	1.261102
August		0	13.420	0.904161	1.285388	1.443354	1.542189	1.125062	1.384627	1.511429	1.158598
September		0	14.350	0.865606	1.229348	1.38	1.474845	1.075357	1.324161	1.445745	1.107076
October		0	16.174	0.805761	1.141801	1.280854	1.369596	0.997438	1.229674	1.343245	1.026187
November		0.016427	17.706	0.739161	1.044783	1.171118	1.252981	0.911289	1.125	1.229565	0.936849
December		0.136802	16.502	0.594534	0.83691	0.93691	1.003401	0.728152	0.900916	0.985543	0.747659
Annual		0.436849	170.989	8.661025	12.25124	13.73578	14.69352	10.69071	13.19253	14.41651	10.99304

Months	r0 /m^2	r1 /m^2	r2 /m^2	r3 /m^2	r4 /m^2	r5 /m^2	r6 /m^2	r7 /m^2	r4w3 /m^2	r4w6 /m^2	r7w3 /m^2
February	1.362955	1.550607	1.718623	1.896356	1.998381	1.626923	1.870648	1.978543	3.017946	3.000912	2.998108
March	1.779757	2.023077	2.242308	2.474899	2.60749	2.122672	2.440688	2.581579	3.766154	3.745937	3.740244
April	2.138664	2.427935	2.691093	2.97166	3.129555	2.547773	2.929352	3.098583	4.417225	4.393359	4.386254
May	2.052834	2.327328	2.579555	2.85	2.999798	2.442308	2.807895	2.970243	4.370496	4.344363	4.340942
June	2.307692	2.61498	2.898381	3.202632	3.370648	2.744332	3.155061	3.337449	4.902232	4.872542	4.869033
July	2.68583	3.044737	3.374696	3.728543	3.924494	3.195344	3.673482	3.88583	5.606699	5.57409	5.568035
August	2.2917	2.594332	2.875506	3.178543	3.34413	2.722874	3.130162	3.311134	4.886319	4.855558	4.853323
September	2.094332	2.37085	2.627935	2.904656	3.056073	2.488259	2.860526	3.025911	4.530918	4.501818	4.500756
October	1.753644	1.985223	2.200405	2.432186	2.558907	2.083603	2.395344	2.533806	3.928503	3.902152	3.903402
November	1.434008	1.623684	1.799798	1.989271	2.093117	1.704251	1.959109	2.07247	3.346099	3.322683	3.325451
December	1.015587	1.151215	1.276113	1.409717	1.484008	1.208097	1.389069	1.469231	2.487409	2.469552	2.472631
Annual	20.917	23.71377	26.28441	29.03826	30.5666	24.88644	28.61073	30.26478	45.26012	44.98311	44.9583

Large District Mosque: II-B

Months		N Vent /m^3	shad. /m^2	w0 /m^2	w1 /m^2	w2 /m^2	w3 /m^2	w4 /m^2	w5 /m^2	w6 /m^2	w7 /m^2
February		0.136289	15.153	0.605461	0.848091	0.947991	1.016445	0.750873	0.912641	0.999454	0.75424
March		0.130899	15.171	0.687827	0.966672	1.081645	1.15884	0.856058	1.040483	1.138631	0.862302
April		0.016427	13.712	0.76265	1.077147	1.207107	1.291735	0.954219	1.159786	1.267807	0.965202
May		0	14.095	0.808607	1.14489	1.283995	1.373215	1.014403	1.232934	1.347042	1.028194
June		0	14.952	0.902172	1.279241	1.435318	1.534521	1.133557	1.377755	1.504782	1.150378
July		0	16.156	0.991418	1.405742	1.577235	1.686262	1.245649	1.513994	1.653597	1.264092
August		0	13.147	0.90597	1.287896	1.446149	1.545182	1.141425	1.387315	1.514387	1.160801
September		0	13.348	0.866409	1.230441	1.38122	1.476146	1.090431	1.325337	1.447041	1.108039
October		0	14.132	0.804594	1.140192	1.279062	1.367664	1.010301	1.227946	1.341342	1.024766
November		0.016427	14.588	0.736329	1.040858	1.166737	1.24829	0.922124	1.120777	1.224941	0.933387
December		0.136802	13.566	0.59145	0.832623	0.932138	0.998264	0.737434	0.896302	0.980487	0.74387
Annual		0.436843	158.115	8.662868	12.25379	13.7386	14.69656	10.85648	13.19527	14.41951	10.99527

Months	r0 /m^2	r1 /m^2	r2 /m^2	r3 /m^2	r4 /m^2	r5 /m^2	r6 /m^2	r7 /m^2	r4w3 /m^2	r4w6 /m^2	r7w3 /m^2
February	1.361397	1.548773	1.71654	1.894155	1.996074	1.624964	1.86834	1.976233	3.012519	2.995528	2.992677
March	1.777491	2.020731	2.23966	2.472033	2.604414	2.120253	2.437755	2.578564	3.763254	3.743045	3.737403
April	2.136106	2.425204	2.688032	2.968247	3.125874	2.544881	2.925857	3.094926	4.417609	4.393681	4.386661
May	2.050474	2.324666	2.576678	2.846665	2.996452	2.439625	2.804727	2.96687	4.369667	4.343494	4.340085
June	2.305192	2.611995	2.895189	3.19907	3.366877	2.741257	3.151455	3.33367	4.901398	4.871659	4.86819
July	2.682743	3.041222	3.370922	3.724222	3.920093	3.191635	3.66927	3.881396	5.606354	5.573689	5.567657
August	2.289272	2.591366	2.872388	3.174957	3.340415	2.719799	3.126693	3.307533	4.885596	4.854801	4.852714
September	2.092033	2.368128	2.624939	2.901443	3.052648	2.485496	2.857338	3.022598	4.528794	4.499689	4.498744
October	1.751684	1.982971	2.198011	2.429515	2.556153	2.081245	2.39261	2.53099	3.923818	3.897496	3.898654
November	1.43245	1.621923	1.797803	1.987011	2.090728	1.702279	1.956961	2.070138	3.339018	3.315669	3.318428
December	1.014512	1.149933	1.274598	1.408197	1.482248	1.206807	1.387408	1.467617	2.480512	2.462735	2.465881
Annual	20.89335	23.68692	26.25477	29.00551	30.53197	24.85825	28.57841	30.23054	45.22854	44.95149	44.9271

Large District Mosque: II-C

Months		N Vent /m³	shad. /m²	w0 /m²	w1 /m²	w2 /m²	w3 /m²	w4 /m²	w5 /m²	w6 /m²	w7 /m²
February		0.136286	16.539	0.606724	0.849828	0.949914	1.018534	0.737155	0.914511	1.001523	0.755859
March		0.130897	17.523	0.694282	0.975603	1.091609	1.16954	0.847931	1.050086	1.149167	0.870263
April		0.016427	17.122	0.775259	1.094626	1.226609	1.312672	0.954167	1.178592	1.288448	0.980729
May		0	16.375	0.814684	1.153305	1.293362	1.383276	1.006868	1.241983	1.356983	1.035697
June		0	17.286	0.908103	1.287443	1.444425	1.544339	1.124971	1.386552	1.514454	1.157686
July		0	19.164	1.00046	1.418247	1.591149	1.701236	1.239224	1.527443	1.668362	1.275236
August		0	15.937	0.914971	1.300345	1.460029	1.560115	1.137931	1.400718	1.529109	1.171884
September		0	15.736	0.873161	1.23977	1.391609	1.487328	1.08431	1.335374	1.458046	1.116357
October		0	15.536	0.805747	1.141753	1.280776	1.369511	0.997356	1.229626	1.34319	1.026232
November		0.016427	15.262	0.733391	1.036724	1.162098	1.243333	0.90431	1.116322	1.220057	0.929817
December		0.136801	13.803	0.586839	0.826178	0.924943	0.990517	0.718879	0.889368	0.972874	0.738222
Annual		0.436851	180.380	8.713506	12.32368	13.81635	14.78023	10.75296	13.2704	14.50207	11.05786

Months	r0 /m²	r1 /m²	r2 /m²	r3 /m²	r4 /m²	r5 /m²	r6 /m²	r7 /m²	r4w3 /m²	r4w6 /m²	r7w3 /m²
February	1.362961	1.550569	1.718451	1.882688	1.998405	1.626879	1.870615	1.961503	3.01694	2.999928	2.980038
March	1.779613	2.023007	2.242141	2.457859	2.607517	2.122779	2.440547	2.560137	3.777057	3.756684	3.729677
April	2.138588	2.428018	2.691116	2.95262	3.129385	2.547836	2.929157	3.074715	4.442057	4.417833	4.387388
May	2.052802	2.327107	2.579499	2.833257	2.999772	2.442369	2.807745	2.949431	4.383048	4.356755	4.332706
June	2.307608	2.614806	2.898405	3.18451	3.370615	2.744191	3.154897	3.314806	4.914954	4.885069	4.859145
July	2.68574	3.044647	3.374715	3.706834	3.924374	3.195216	3.673349	3.85877	5.625609	5.592736	5.560006
August	2.29164	2.594077	2.875399	3.161731	3.343964	2.722779	3.130068	3.290433	4.904078	4.873073	4.850548
September	2.094214	2.370615	2.62779	2.889522	3.055809	2.488155	2.860364	3.007062	4.543136	4.513855	4.494389
October	1.753554	1.984966	2.200456	2.419362	2.55877	2.083371	2.395216	2.517768	3.928281	3.90196	3.887279
November	1.433986	1.62369	1.799772	1.978588	2.092938	1.7041	1.958998	2.059226	3.336272	3.312996	3.302559
December	1.015535	1.151253	1.276082	1.401595	1.483827	1.2082	1.388838	1.458998	2.474344	2.4567	2.449515
Annual	20.91617	23.71276	26.28337	28.86879	30.56538	24.88542	28.60957	30.05308	45.34561	45.06744	44.83331

Central Mosque: III-A

Months		N Vent /m^3	shad. /m^2	w0 /m^2	w1 /m^2	w2 /m^2	w3 /m^2	w4 /m^2	w5 /m^2	w6 /m^2	w7 /m^2
February		0.13629	7.075	0.602611	0.844146	0.943587	1.011765	0.747389	0.908393	0.994806	0.750628
March		0.1309	6.965	0.674821	0.948594	1.061478	1.137159	0.840057	1.021033	1.117288	0.846187
April		0.016427	6.145	0.737432	1.042095	1.16802	1.249785	0.923214	1.122095	1.226456	0.934103
May		0	6.455	0.79561	1.126829	1.263859	1.35165	0.998422	1.213515	1.325739	1.012085
June		0	6.856	0.889182	1.261191	1.415194	1.512912	1.11759	1.35835	1.483486	1.13426
July		0	7.366	0.972324	1.379211	1.547647	1.654519	1.222166	1.485466	1.622296	1.240458
August		0	5.944	0.886872	1.261363	1.416571	1.513343	1.117948	1.35878	1.483085	1.137195
September		0	6.090	0.851793	1.210129	1.35858	1.451793	1.072453	1.303501	1.423085	1.089921
October		0	6.601	0.800976	1.135151	1.273443	1.361693	1.005839	1.222525	1.335395	1.02014
November		0.016427	6.911	0.740846	1.047131	1.17373	1.255811	0.927676	1.127518	1.232339	0.938769
December		0.136803	6.473	0.599613	0.843974	0.944792	1.011908	0.747475	0.908508	0.993874	0.753767
Annual		0.436843	72.958	8.55208	12.09981	13.5669	14.51205	10.72022	13.02966	14.23783	10.8575

Months	r0 /m^2	r1 /m^2	r2 /m^2	r3 /m^2	r4 /m^2	r5 /m^2	r6 /m^2	r7 /m^2	r4w3 /m^2	r4w6 /m^2	r7w3 /m^2
February	1.363014	1.550685	1.718569	1.882801	1.998478	1.626941	1.870624	1.978539	3.010243	2.993284	2.990304
March	1.779604	2.023135	2.242314	2.457839	2.607458	2.122831	2.440639	2.581583	3.744617	3.724747	3.718742
April	2.138661	2.428006	2.691172	2.952816	3.129528	2.547793	2.929224	3.098478	4.379313	4.355984	4.348263
May	2.052816	2.327245	2.579604	2.833333	2.999848	2.442466	2.807915	2.97032	4.351498	4.325587	4.32197
June	2.307763	2.614916	2.898478	3.184779	3.370624	2.744292	3.154947	3.337443	4.883537	4.85411	4.850355
July	2.685845	3.044749	3.374734	3.707002	3.924505	3.195282	3.673364	3.885845	5.579025	5.546801	5.540364
August	2.291781	2.594216	2.875647	3.161948	3.34414	2.722831	3.130137	3.311263	4.857483	4.827225	4.824606
September	2.094368	2.370776	2.627854	2.88965	3.056012	2.48828	2.860578	3.026027	4.507806	4.479097	4.477821
October	1.753577	1.985236	2.200457	2.419635	2.559056	2.083562	2.395282	2.53379	3.920749	3.894451	3.895483
November	1.434094	1.623744	1.799848	1.978691	2.092998	1.70411	1.959209	2.072451	3.348809	3.325337	3.328261
December	1.015525	1.151294	1.276104	1.401674	1.483866	1.208219	1.389041	1.469254	2.495774	2.47774	2.481162
Annual	20.9172	23.714	26.28478	28.87017	30.56682	24.88661	28.61096	30.26499	45.07887	44.80465	44.77704

Central Mosque: III-B

Months		N Vent $/m^3$	shad. $/m^2$	w0 $/m^2$	w1 $/m^2$	w2 $/m^2$	w3 $/m^2$	w4 $/m^2$	w5 $/m^2$	w6 $/m^2$	w7 $/m^2$
February		0.136287	14.806	0.604915	0.847328	0.947135	1.015529	0.750197	0.911819	0.998557	0.753511
March		0.130897	14.952	0.681803	0.958263	1.072259	1.148765	0.848615	1.031436	1.128714	0.854808
April		0.016426	13.603	0.75	1.059533	1.187451	1.270633	0.93863	1.140839	1.247033	0.949563
May		0	14.350	0.801411	1.134836	1.272767	1.361168	1.005504	1.222117	1.335189	1.019219
June		0	15.317	0.894654	1.268742	1.423589	1.52194	1.124263	1.366458	1.492406	1.140994
July		0	16.466	0.980888	1.391043	1.56082	1.668648	1.232637	1.498179	1.636265	1.250988
August		0	13.147	0.895799	1.2737	1.430296	1.528171	1.128859	1.372042	1.49765	1.148146
September		0	13.238	0.858757	1.219755	1.369282	1.46334	1.080971	1.313839	1.434444	1.098491
October		0	13.968	0.80277	1.137596	1.276149	1.36455	1.008	1.22515	1.338288	1.022374
November		0.016426	14.314	0.738983	1.044496	1.17078	1.252645	0.925341	1.124686	1.229241	0.936514
December		0.136801	13.366	0.596033	0.838963	0.939199	1.005855	0.743042	0.903119	0.987971	0.749406
Annual		0.436838	157.641	8.606014	12.17425	13.64973	14.60124	10.78606	13.10968	14.32576	10.92401

Months	r0 $/m^2$	r1 $/m^2$	r2 $/m^2$	r3 $/m^2$	r4 $/m^2$	r5 $/m^2$	r6 $/m^2$	r7 $/m^2$	r4w3 $/m^2$	r4w6 $/m^2$	r7w3 $/m^2$
February	1.362868	1.550485	1.718437	1.896247	1.998281	1.626761	1.870405	1.978416	3.013811	2.996838	2.993946
March	1.77946	2.022898	2.24206	2.474681	2.607207	2.122525	2.440369	2.581327	3.755971	3.73592	3.730091
April	2.138335	2.427662	2.690756	2.971254	3.129042	2.547459	2.928823	3.098063	4.399675	4.376075	4.368696
May	2.052498	2.326875	2.579127	2.849366	2.999299	2.441943	2.807392	2.969688	4.360467	4.334488	4.330856
June	2.307247	2.614423	2.897878	3.202037	3.370003	2.743803	3.154382	3.336764	4.891943	4.862409	4.858704
July	2.685345	3.044102	3.374114	3.727743	3.923803	3.194655	3.672743	3.88507	5.592451	5.560068	5.553718
August	2.291228	2.593659	2.874927	3.177758	3.343367	2.722203	3.129457	3.310455	4.871538	4.841017	4.838626
September	2.093846	2.370221	2.62726	2.904003	3.055345	2.487693	2.859863	3.02527	4.518685	4.489789	4.48861
October	1.753239	1.984727	2.199958	2.431663	2.558418	2.083088	2.394728	2.533231	3.922967	3.896706	3.89778
November	1.433726	1.623375	1.799413	1.988785	2.0926	1.703802	1.958714	2.07199	3.345245	3.321841	3.324635
December	1.015393	1.15102	1.275803	1.409527	1.48365	1.207949	1.38872	1.469005	2.489505	2.471621	2.47486
Annual	20.91319	23.70945	26.27974	29.03307	30.56101	24.88189	28.60559	30.25928	45.16225	44.88677	44.86053

Central Mosque: III-C

Months		N Vent /m³	shad. /m²	w0 /m²	w1 /m²	w2 /m²	w3 /m²	w4 /m²	w5 /m²	w6 /m²	w7 /m²
February		0.136288	16.849	0.622759	0.872143	0.974821	1.045268	0.756429	0.938482	1.027857	0.775784
March		0.130898	17.997	0.714607	1.003839	1.123125	1.203393	0.872321	1.080536	1.1825	0.895459
April		0.016427	17.925	0.801259	1.130804	1.266964	1.355982	0.985446	1.2175	1.331161	1.012941
May		0	16.247	0.825571	1.168482	1.310268	1.401429	1.02	1.258304	1.374821	1.049392
June		0	16.995	0.917161	1.300089	1.458571	1.559464	1.135893	1.400179	1.529375	1.169158
July		0	19.146	1.015518	1.439196	1.614554	1.726339	1.257321	1.55	1.693125	1.294131
August		0	16.393	0.934946	1.328214	1.491071	1.593393	1.161964	1.430625	1.561875	1.196747
September		0	16.156	0.892196	1.266339	1.421161	1.519107	1.107232	1.363929	1.489375	1.140107
October		0	15.627	0.818705	1.159821	1.300893	1.391161	1.012946	1.249018	1.364464	1.042449
November		0.016427	15.226	0.743366	1.050625	1.177589	1.26	0.916339	1.13125	1.236429	0.942324
December		0.136802	13.548	0.592152	0.833571	0.933214	0.999464	0.725268	0.897321	0.981607	0.744998
Annual		0.436838	182.16	8.878304	12.55321	14.0725	15.05518	10.95134	13.51732	14.77277	11.26349

Months	r0 /m²	r1 /m²	r2 /m²	r3 /m²	r4 /m²	r5 /m²	r6 /m²	r7 /m²	r4w3 /m²	r4w6 /m²	r7w3 /m²
February	1.362923	1.550619	1.71858	1.896367	1.998431	1.626837	1.87052	1.97853	3.043699	3.026288	3.023798
March	1.779604	2.023039	2.242279	2.474897	2.607432	2.122709	2.440545	2.581503	3.810825	3.789932	3.784896
April	2.138563	2.427911	2.691082	2.971594	3.129397	2.547729	2.929149	3.098431	4.485379	4.460558	4.454413
May	2.052766	2.327168	2.579521	2.849794	2.999752	2.442279	2.807762	2.970107	4.401181	4.374574	4.371536
June	2.307597	2.614864	2.898348	3.20256	3.37052	2.744261	3.154831	3.337242	4.929985	4.899895	4.896706
July	2.685714	3.044509	3.374566	3.728324	3.92436	3.195128	3.673245	3.885632	5.650699	5.617485	5.611971
August	2.29166	2.594137	2.875392	3.178282	3.343931	2.722709	3.129975	3.311065	4.937323	4.905806	4.904458
September	2.09422	2.370603	2.627746	2.904542	3.055904	2.488109	2.860363	3.025764	4.575011	4.545279	4.544871
October	1.753509	1.985054	2.20033	2.432122	2.558877	2.083485	2.395128	2.533691	3.950038	3.923341	3.924852
November	1.433939	1.623617	1.799752	1.9891	2.092981	1.704129	1.959042	2.072337	3.352981	3.32941	3.332337
December	1.015524	1.151197	1.27597	1.409744	1.483898	1.208092	1.388935	1.469199	2.483362	2.465505	2.468663
Annual	20.91594	23.71255	26.28315	29.03683	30.56499	24.88514	28.60933	30.26317	45.62017	45.33776	45.31835

8.3.5 The passive cooling strategy, the improvement measures and the setting target strategy potential savings for all Jeddah's mosques and their contribution to the national energy and emissions levels

It equally important to give an estimation of the potential savings of the proposed measures, passive cooling and setting target strategies on a city scale. In order to do a proper estimation on the national potential savings of air conditioning energy, money and CO_2 emissions, and CFCs emissions for each proposed measure and the passive cooling and the setting target strategies for the whole city, the number of air conditioned mosques under each category has to be known. Unfortunately, information about these numbers are not available and therefore, there is a need to do some estimations. The author has relied on the sample surveyed (Chapter Five) assuming that the sample is presenting the whole air conditioned mosques in the country in terms of the sizes and the correlated numbers. This assumption was later discussed and agreed to be correct by the officials in the Ministry of Haj and Awkaf (endowment). After analysing the sample surveyed, the estimated sizes of air conditioned mosques and their numbers in Jeddah is calculated and presented in table 8.45.

The estimated amounts of air conditioning energy, money, CO_2 emissions, and CFCs emissions for each category in Jeddah is shown in Table 8.46. It was found that the amount of air conditioning energy used in all mosques was about 84,140,898 Kwh, costing 4,207,045 Sri (£=725352.5) and emitting 4964 tonnes of CO_2 and approximately 3.56 tonnes of CFCs.

Table 8.45 Estimated number of mosques under each category in Jeddah

Mosque Category	%	No. of mosques
I-A	4.77	41
I-B	4.27	41
I-C	4.27	41
II-A	16.77	161
II-B	39.79	382
II-C	10.52	101
III-A	9.47	91
III-B	8.43	81
III-C	2.29	22

Table 8.46 Estimated air conditioning energy consumption, money, CO_2 emission and CFCs emissions under each mosque category in Jeddah.

		Individual mosque				All mosques			
Mosque category	No. of mosques	Ac. energy consumn. (Kwh)	Cost in (Sri)	CO_2 emisn. in (Kg)	CFCs emisn. in (Kg)	Ac. energy consumn. (Kwh)	Cost in (Sri)	CO_2 emisn. in (Kg)	CFCs emisn. in (Kg)
I-A	41	15231	761.55	898.629	2.352	624471	31223.55	36843.79	96.43199
I-B	41	47420	2371	2797.78	2.93	1944220	97210.99	114709	120.13
I-C	41	72675	3633.75	4287.825	3.451	2979675	148983.7	175800.8	141.491
II-A	161	46123	2306.15	2721.257	3.13	7425802	371290.1	438122.3	503.9299
II-B	382	90687	4534.35	5350.533	3.422	34642437	1732122	2043904	1307.204
II-C	101	105908	5295.4	6248.572	4.13	10696705	534835.2	631105.6	417.1299
III-A	90.9	64894	3244.7	3828.746	4.469	5905250	295262.5	348409.8	406.6718
III-B	80.9	119074	5953.7	7025.366	5.123	9644422	482221.1	569020.9	414.9384
III-C	21.9	467314	23365.7	27571.53	6.95	10277917	513895.9	606397.1	152.8555

The total annual savings for each measure and the passive cooling and the setting target strategies on a city scale as well as the percentage of saving on national scale is calculated and shown in Table 8.47. The percentages of savings in conditioning, money and CO_2 and CFCs emissions are found much higher on city level. The percentages due to passive cooling strategy is 2.9 times the ones achieved by best performance measure of (R4 W3) and is 1.65 time the one obtained by the setting target strategy. Moreover, the percentage of saving due to the setting strategy is 1.65 time the best performance measure of R4 W3. As far as the percentages of CFCs emission are concerned, it was found that the percentage of saving as related to the passive cooling strategy is 3.11 times the one achieved by best performance measure of R4 W3.

The results shows that the amounts of savings from the strategies and the proposed measures have little contribution to the national energy, money and CO_2 (1.4%, 2.64%, 4.09%) and CFCs (0.96% and 3.019%) emissions levels.

In conclusion, the proposed improvement measures and the passive cooling strategy as well as the setting target strategy have shown to contribute positively in the reduction of energy, money and CO_2 and CFCs emissions levels at local and national levels.

In this chapter two important topic have been addressed; (1) the applications of the proposed passive cooling strategy and the proposed improvement measures in nine selected mosques and (2) the calculation of their potential savings in air conditioning

Table 8.47 The total annual savings for each measure, passive cooling strategy and the setting target strategy on a city scale and the percentages of saving in a national scale.

Measure and strategies	Cost (£)	Energy saved (Kwh)	Money saved (£)	CO_2 emn. saved (Tonnes)	% saving on city level (CO_2, £,Kwh)	% saving on national level (CO_2, £,Kwh)	CFCs em. saved (Tonnes)	% saving on city level (CFCs)	% saving on national level (CFCs)
N. ventilation	0	1,645,630	14,186	97.092	1.9	0.097	0.038	1.08	0.05
Shading	482,836	6,235,231	53,751	367.8	7.4	0.37	0.091	2.57	0.12
W0	2,270,978	4,560,512	39,314	269.070	5.42	0.27	0.014	0.4	0.019
R0	3,598,736	10,919,406	94,132	644.244	12.97	0.64	0.262	7.48	0.36
R0 W0	5,869,714	15,480,391	133,446	913.343	18.39	0.91	0.591	16.88	0.82
R4 W3	13,450,569	23,703,306	204,338	1398.495	28.17	1.40	0.976	27.88	1.36
R4 W6	14,813,156	23,558,516	203,090	1389.952	28	1.39	0.967	27.62	1.35
R7 W3	11,561,232	23,537,480	202,909	1388.711	27.9	1.39	0.969	27.68	1.36
Passive cooling strategy	0	68,913,945	594,085,7	4065.92	81.9	4.09	3.019	86.25	4.23
Setting target strategy	0	41,548,503	358,176.7	2451.36	49.38	2.46	unknown	-	-

energy, money and CO_2 and CFCs emissions by using the methods discussed in Chapter Seven. The last part of the chapter was devoted to (a) discussing the passive cooling strategy and the measures potential savings in all nine mosque categories and (b) using the results achieved in (1) producing the potential savings tables which can be used by the architect in calculating the different savings in any mosque with a selected measure and (2) estimating the potential savings of each measure and passive cooling strategy when applied to all Jeddah existing air conditioned mosques as well as their contribution to the national air conditioning energy and CO_2 and CFCs emissions levels.

CHAPTER NINE: SUMMARY AND RECOMMENDATIONS

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9.1 Summary

At present, large numbers of existing or new mosques are air conditioned in every city in Saudi Arabia. This is a result of the rapid growth of population, a rapid increase in oil production, the continuous application of the Government scheme in constructing more mosques and installing air conditioners in the majority of them all over the country. This process is carried out due to the fact that existing mosques both new and old have failed to provide comfort conditions inside the prayer hall due to poor thermal design. New mosques are built with poor standards of construction and finishing because of lack of supervision and the absence of building regulations. Old mosques, although adopting regional architectural values, could not adapt the high temperatures currently our cities experiencing. Unfortunately, the installation of these air conditioners is commonly associated with (a) a huge increase in demand for energy which leading to huge emissions of CO_2 and (b) substantial amounts of CFCs emissions.

The intention of this thesis has been to investigate some aspects of passive cooling in existing air conditioned mosques and their potential savings in air conditioning energy, money and CO_2 and CFCs emissions levels. In specific, the study has focused on the determination, performances and the applications of the two important aspects of passive cooling of (1) the passive cooling strategy and (2) the passive cooling improvement measures in existing air conditioned mosques. This chapter aims to summarise the main findings of the study and to recommend some important measures for reducing the amounts of air conditioning consumption as well as emissions of CO_2 and CFCs.

In determining the proposed passive cooling strategy in mosques (Chapter Three), three important topics have been analysed. These topics were the climatic data for 13 years for the city of Jeddah, the comfort level needed in mosques and the prayer times for Jeddah. It was found that the passive cooling strategy as related to air movement (ventilation) and thermal mass has the ability to provide comfortable conditions inside the mosque for substantial numbers of prayers showing some promising potential for savings in air conditioning energy, money and CO_2 and CFCs emissions. As for ventilation, it can be used in the following prayers:

i. 20 Fajr prayers in August.

ii. 10 Duhur prayers in 5 days before end March and first 5 days on December.

iii. 10 Asr prayers in the first 5 days of April and last 5 days of November.

iv. 160 Magrib prayers from the last ten days of March to the first 20 days of May and from the first 24 days of October to the first two days of December.

v. 71 Isha'a prayers from the last 20 days of April to mid June and from the first of October the first 20 days of November.

While the passive cooling strategy related to thermal mass can be effective in the following prayers:

i. 51 Duhur prayers from last 3 days of March to the end of May and from the first 10 days of September to the end of November.

ii. 153 Asr prayers from last 25 days of April to the first 20 days of June and from first of September to last 25 days of November.

iii. 102 Magrib prayers from the last 11 days of May to the first 7 days of October.

iv. 153 Isha'a prayers from the last 15 days of June to the end of September.

On the other hand, mechanical air cooling systems are needed in 104 Duhur prayers from first of June to the last 20 days of September. And 75 Asr Prayers from last 10 days of June till the end of August.

In determining the passive cooling improvement measures for existing mosques, three important subjects have been dealt with. These subjects are as follows:

1. The review and evaluation of passive cooling systems in Jeddah's mosques (Chapter Four).
2. The definition of passive cooling systems which need improvement (Chapter Five).
3. The detail analysis and understanding of the passive cooling systems defined in Chapter Five so as to define the various improvement measures (Chapter Six).

From the discussion on the different cooling systems used in existing air conditioned mosques (Chapter Four), three important points can be highlighted:

1. The mechanical cooling system seems to be most welcomed and widely used in either old or modern existing mosques in Jeddah. This system is very effective in improving the internal environment of the mosques, but it affects the environment in three ways:

a. Emitting too much CO_2 due to the high energy used to run the system.

b. Emitting CFCs from the compressors normally used in the system.

c. Drain out heat.

2. It would be unrealistic to expect all mosques to be cooled passively and the use of mechanical cooling systems to be completely abandoned, yet it is possible to minimise the cooling load in order to reduce these three emissions of CO_2, CFCs and heat.
3. Both modern passive cooling systems such as insulation, glazing, shading devices and traditional passive cooling systems are used in existing mosques. Unfortunately, those modern ones were used ineffectively due to the lack of understanding. Therefore, there is a need for discovering the potential of improving these passive cooling systems in reducing the environmental impacts in existing mosques.
4. Various passive cooling systems are used in existing mosques.

Chapter Five comprises the determination of existing passive cooling systems which need improvements. For this purpose, a survey was carried out of existing mosque in Jeddah between 15 June 1992 and 15 September 1992, collecting information about important topics of; the physical characteristics of these mosques, their management in terms of using the different appliances, air conditioning energy consumption levels as well as the amounts of emissions of CO_2 and CFCs related, and the various passive cooling systems used. The primary method used in collecting the information was personal observation, personal interview, and archives documents (detailed drawings) for each mosque to a sample of 48 mosques. The results of the survey are reported in detail in Chapter Five. The summary of these findings is as follows;

1. Passive cooling systems: typical systems used are for walls, roofs and windows as far as heat rejection strategy is concerned. For the heat sink strategy; earth, radiative and ventilation cooling systems are used in nearly all existing air conditioned mosques. Evaporative cooling systems are not used.

2. Air conditioning systems and energy consumption: several important points are found:
    a. Lack of environmental awareness regarding the emissions of CO_2 and CFCs as related to air conditioning systems. Strong awareness on the economic side of the problem.
    b. Air conditioning systems are used continuously for at least 48 weeks all year round and left unused in January.
    c. On yearly basis, the number of air conditioners used are found to range between half in fairly hot season and all of the units during the summer seasons.
    d. Lack of maintenance to these a/c units and the re-injection process of these systems with the refrigerant is found to be taken every 5 to 6 years.
    e. The actual weight of CFCs used in each a/c unit in most of the surveyed mosques can hardly be traced due to the missing or

deteriorated specification tag.

f. The annual CFCs emission ranged between 16.5% to 20% of the whole amount installed in the system

g. The typical electrical appliances in existing air conditioned mosques are the sound amplifiers, lights fans and air conditioning systems. Air conditioning systems are the main contributors to the current electricity consumption.

h. A new classification of existing air conditioned mosques under the three mosque categories (Small, Large District and Central mosques) based on air conditioning energy consumption levels as follows:

1. Low air conditioning energy consumption: up to 16.77 Kwh or 0.99 Kg of CO_2.
2. Moderate to high air conditioning energy consumption: from 16.94 Kwh to 33.72 Kwh or 1 to 1.99 Kg of CO_2.
3. High air conditioning energy consumption: over 33.89 Kwh or over 2 Kg of CO_2.

i. Over 90% of the surveyed mosques experience high air conditioning energy consumption.

3. Selection of case study mosques: nine mosques have been defined to represent the stock of air conditioned mosques in Jeddah based on volume, energy consumption and numbers of worshippers criteria. These are Zaid Al-Khair, Al-Majd, Al-Forkan (Small district mosques), Al-Rida, Ibn Abbas, and Al-Taqwa (Large district mosques) and Amodi, T. Lami, Shoaibi

(Central mosques).

The high air conditioning energy in mosques was studied in detail to find out the associated factors. The high air conditioning energy cannot be circumscribed by only one factor, but actually are as a result of several factors. The cross-tabulation of these factors; air conditioning types, number of appliances, numbers of worshippers, volume of the prayer halls, and the adopted passive cooling systems of insulation values (thermal transmittance U-value) of the mosque envelope, exposure to the outdoor environment, and allowing cross ventilation against the level of air conditioning energy consumption, showed positive relationships on affecting the degree of suffering high air conditioning energy. It revealed that the increase in using more than one air conditioning system type, numbers of appliances, numbers of worshippers and volume of prayer hall is associated with an increase in high air conditioning energy in the mosque. Furthermore, it showed that there were deficiencies in the three passive cooling systems adopted in mosque summarised below:

1. Using poor building materials in the envelope which gives higher thermal transmittance values.
2. Poor shading and increase of exposed surfaces to the outdoor environment.
3. Limited use of night cross-ventilation.

Understanding and analysing the principles, strategies and means of these systems have then helped in the definitions of the proposed measure of improvements (Chapter Six). Three passive cooling improvement measures has been suggested; increase insulation values of mosques' envelope by adding a composition of building and insulation materials for walls and roofs, increase shading by complete shading of windows, increase night ventilation rates by ventilating the mosque for the whole night, i.e. 7 hours. The justification of this selection are highlighted below.

Firstly, the proposed improving measure of increasing insulation values of walls and roofs by adding building and insulation materials will be placed from the mosque interior. These building and insulation materials are easy to erect, does not require too much space and does not demand heavy structural support to rely on, and are available in the local market. Moreover, the additions of these materials will have no effect on the expensive marble facades. It is suggested to add calcium silicate blocks and plaster boards for existing walls and cork and plaster boards suspended ceiling for roof. On the other hand, the addition of glazing to existing windows cannot be carried out due to the fact that the current frames are designed only to fit the 6 mm glazing used.

Secondly, increase shading for existing windows by using the highly effective shading devices available in the market. They are easy to erect and will keep the current marble facades unaffected. While the increase of shading of existing walls and roofs may require the use of rigid elements capable of providing perfect shading with high resistance to the harsh climatic conditions of high temperature and high humidity. These rigid elements such as *Riwaq* walls (additional wall located at least 2 to 3 metres away from the existing walls) or double roof require structural support where most existing air conditioned mosques cannot provide. In addition, these shading elements demand space around the mosque which may not be available for all mosques. Plants are not effective for proper shading as far as the diffused and reflected solar radiation are concerned. Moreover, plants needs water which is not available in the region in large quantities and they are not effective as a short term solution. It is suggested to use the effective shading device, of 45° inclined tested by Evans for existing windows.

Finally, increased night ventilation rate by leaving existing windows open at night for long hours without the use of fans. Windows in existing mosques are abundant and can be found in most of the mosques' walls. Moreover, mosques are never used between Isha'a and Fajr prayers. Fans are not available in all existing mosques. It is suggested that the mosque's windows should be left opened for 7 hours.

Chapter Seven discusses the calculation methods to predict the amount of savings in air conditioning energy, money and CO_2 and CFCs emissions as related to the proposed passive cooling strategy and the proposed passive cooling improvement measures. In calculating the amount of air conditioning energy savings due to the proposed strategy, the method is to sum all the air conditioning energy consumption during the periods at which this passive cooling strategy is applicable. This period is found to be the whole months of the year except June, July, August and September for Duhur prayer and the last 10 days of June and whole months of July and August for Asr prayer.

The method of calculating the performances of the proposed improvement measures is in fact a modified version of the Passive Cooling Evaluation method (PACE) developed by Dr. Baker at Cambridge University. The method was originally designed to predict the potential saving in air conditioning energy. The method has been modified to predict savings in money and CO_2 and CFCs emissions and the cost effectiveness of the proposed measures within the context of an intermittent occupancy pattern of mosque.

Chapter Eight is composed of two sections. The first one is studying the applications of the proposed passive cooling strategy and the proposed passive cooling improvement measures in nine case study mosques identified in Chapter Five estimating their potential savings which can be achieved by using the calculation method discussed in Chapter Seven. The second part discusses (1) the strategy and the measures performances in each mosque category, (2) the development of potential saving tables easy to predict the amount of savings in air conditioning energy, money, CO_2 and CFCs emissions that can be achieved under the proposed measures of improvements to any air conditioned mosque, (3) the potential savings of the strategy and the improvement measures at the city level as well as their contributions to the total national air conditioning energy consumption as well as CO_2 and CFCs emissions.

The proposed passive cooling strategy is found to give savings around 80s% in air conditioning energy, money and CO_2 and CFCs emissions at no extra cost. While the proposed measures of night ventilation and complete shading are found to give very little savings in air conditioning energy, money and CO_2 and CFCs emissions compared to the measures of using the modified walls and roofs proposed. Furthermore, it was found that the potential savings under different combinations of modified walls and roofs were the highest. As far as the cost effectiveness of these measures is concerned, the measure of complete shading is found to be cost effective while using the modified walls and roof (individually or combined) are found to be not cost effective due to the long payback period. This is due to the following factors:

1. Electricity is sold very cheap in Saudi Arabia (1 Kwh = 0.008 £).
2. The costs of labour and building materials are high due to the absence of local labour force and local building materials.

Unfortunately, this scenario is expected to continue in the future due to the fact that (1) energy is abundant in the country and there is no intention from the Government to put electricity price up. Furthermore, it is highly unlikely that both local labour and building materials would be available in short time. Based on these circumstances, it seems obvious to put an emphasis on the management strategy in existing air conditioned mosques. Two important management strategies can be used. The first one is the use of the proposed passive cooling strategy discussed before and the second one is the adoption of the setting target strategy.

The setting target strategy is a strategy aimed at reducing air conditioning energy consumption levels in mosques mainly with mid to high consumption. The strategy is based on setting the level of air conditioning energy consumption per cubic metre similar to the level used in low air conditioning energy consumption mosques. It was found that by implementing this strategy a higher percentages of savings can be achieved (50% to 74%).

As for the results related to the improvement measures performances, the author has managed to produce a comprehensive set of potential saving tables to predict the potential savings in any mosque under different measures of improvements. These tables can be used by the architect, the mosque managers and the Ministry of Awkaf.

As for the contribution of the passive cooling strategy, the setting target strategy and the improvement measures potential to both air conditioning energy and CO_2 and CFCs emissions levels at the city and national scales, the contribution was found to be reasonable within the city scale and very little on the national scale. On the city level, the percentage of savings was about 81.9%, 49.38% and 28% and the saving percentages in CFCs emissions were 86.25% and 77.88%. While at a national level, the saving percentages in air conditioning energy money and CO_2 emissions were 4.04%, 2.64% and 1.9% with only 0.96 and 3% savings in CFCs emissions.

8.2 Recommendations

The recommendations of this study fall into three parts and are entirely related to existing air conditioned mosques . These are

1. Design concept
2. Management
3. Areas requiring further research

8.2.1 Design concept

Recommendations related to additional design concepts in existing air conditioned mosques are as follows.

1. The open areas around the mosque should be landscaped. A careful planting of

green areas would reduce the reflected solar radiation and provide some shade for walls, windows, and roofs. Water used for ablution can be reused for irrigation.

2. The concept of zoning within the prayer hall should be introduced, due to the low numbers of worshipper's attendance in some prayers. The place below the mezzanine level is considered to be appropriate.

3. The number of entrance in existing mosques should be eliminated to one so as to prevent the penetration of hot air through the air drifting process.

4. Existing open courtyards should be closed properly with opaque materials so as to prevent the penetration of hot air as well as solar radiation.

8.2.2 Management

Recommendations related to management involve several important concepts about building regulation, air conditioning units, and others. These are summarised below.

1. The government should encourage the mosque owner through building regulation, to keep existing mosque to specifications that would ensure maximum reductions in air conditioning energy, CO_2 emissions, and CFCs emissions. Such specifications should include wall number 7 (the use of 75mm extruded polystyrene and calcium silicate blocks and roof 3 (the use of 75mm extruded polystyrene and plaster board)

giving roughly similar saving amounts to the combination of wall 3 and roof 4 and cost less.

2. The government should encourage the mosque owner to adopt the two management strategies which involves the use of the proposed passive cooling strategy and the proposed setting target strategy.

3. The government should also monitor the use of these strategies by conducting several visits to mosques. These visits should be carried out by the staff members in The General Directorate of Awkaf and Mosques in Jeddah's Region.

4. The government should set approximately the amounts of air conditioning energy consumption for each mosque (10 to 12 Kwh per cubic metre) and should also review the monthly electricity bills of these mosques under the scheme. An extra charge may be appropriate with any exceeding in energy consumption.

5. Encourage the use of fans with the air conditioning units in order to achieve the comfort level in short time. This would mean less air conditioning energy is used.

6. Encourage the mosque management to relocate the outdoor unit of the air conditioning system (compressors) to locations far from walls in order to reduce part of the cooling load related to heat gained by walls.

7. Increase the numbers of well trained local labours regarding the installing and

servicing of air conditioners. This may be achieved by improving the current curriculum of Saudi vocational institutes to include this specialisation.

8. Establish high standards and specifications to govern the quality of air conditioners imported or locally manufactured.

9. Encourage the air conditioning companies to promote first class services regarding the installation and maintenance of their products as well as controlling the current private air conditioning workshops in the city.

10. Ensure to properly close any sources of infiltration particularly holes and cracks around doors and windows.

11. Install the necessary device to close the door after being opened.

12. Increase awareness of energy and environment conservation in general and as related to the use of air conditioning in our daily life in particular. This can be achieved within the mosque domain through Jum'a sermon.

8.2.3 Areas requiring further research

From the analysis of the previous findings of this study it is evident that the contemporary situation of existing air conditioned mosques in Jeddah and the whole of Saudi Arabia require more research into areas of application of passive cooling measures which at present not fully understood. Such research would assist this study if it were available. Some areas to consider are:

1. Study on the effect mechanical night ventilation and the reductions in air conditioning energy, CO_2 emissions and CFCs emissions.
2. Comprehensive study of the environmental costs concerning the production of different building materials in Saudi Arabia.
3. The application of the proposed insulation materials to other existing air conditioned buildings under longer time of occupancy such as houses, schools, etc.
4. The application of complete shading of walls through the use of Riwaq concept is highly needed as this may affect the design of future air conditioned mosques all over the world.
5. Field study to measure the intensity of solar radiation falling on the different walls of existing air conditioned mosques. At the present, data are available for horizontal planes only.
6. The potential savings of using the proposed insulation materials as related to fuel consumption, excavation, and processing.
7. The method developed in calculating the potential savings in air conditioning energy and emissions of CO and CFCs depends entirely on correction factor not tested. Testing and validating this factor is urgently needed.
8. Embodied energy of materials is an important subject to be looked at.

Finally, since this study was concerned with potential savings in air conditioning energy, money and CO_2 and CFCs emissions in existing air conditioned mosques and was limited to Jeddah, the findings and recommendations must be considered as suggestive rather than conclusive. However, this study should be seen as one of a series of studies in Jeddah, Saudi Arabia, and the whole Islamic world. It provides some useful tool and techniques for evaluating and improving both energy and environmental performance of building in general by adopting some important aspects of passive cooling.

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Appendix 1.A

The savings calculation of the proposed passive cooling strategy in Al-Rida mosque

1. Average monthly air conditioning energy consumption (Kwh) and the number of air conditioners used in Rida mosque.

Month	Air conditioning energy (Kwh)	Numbers of A/C units
January	0	0
February	2209	4
March	2793	4
April	3478	5
May	4193	5
June	7373	6
July	5981	6
August	5757	6
September	4974	5
October	4599	5
November	2621	4
December	2145	4
Total	46123	54

2. Annual air conditioning energy saved (due to the proposed passive cooling strategy) =

   Current total annual air conditioning energy consumption - air conditioning energy consumption for Duhur prayer (during June, July, August, September) and for Asr prayer (during 10 days of June, July and August)

3. Air conditioning energy consumption (Kwh) for Duhur prayer in:

   a. June = 7373/5 = 1474.6
   b. July = 5981/5 = 1196.2
   c. August = 5757/5 = 1151.4
   d. September = 4974/5 = 994.8
   Total = 4817 Kwh

4. Air conditioning energy consumption (Kwh) for Asr prayer in:

   a. 10 days of June = (7373/5)/3 = 491.533
   b. July = 5981/5 = 1196.2
   c. August = 5757/5 = 1151.4
   Total = 2839.13 Kwh

5. Annual air conditioning energy saved (due to the proposed passive cooling strategy) =

   46123 - (4817+2839.133) = 38466.87 (83.4%) Kwh

6. CO_2 emission saved = 38466.87 x 0.059 = 2269.5 Kg

7. Money saved = 38466.87 x 0.05 = 1923.3 Sri (£ 331.6)

8. CFCs emission saved = Annual CFCs emissions - CFCs emissions during Duhur prayer (June, July, August, September) and Asr prayer (during 10 days of June, July and August)

9. CFCs emission related to Duhur prayer in
   a. June = (0.058 x 6)/ 5 = 0.0696
   b. July = (0.058 x 6)/5 = 0.0696
   c. August = (0.058 x 6)/5 = 0.0696
   d. September = (0.058 x 5)/5 = .058
   Total = 0.2668 Kg

10. CFCs emission related to Asr prayer in
   a. 10 days of June = [(0.058 x 6)/ 5]/3 = 0.0232
   b. July = (0.058 x 6)/5 = 0.0696
   c. August = (0.058 x 6)/5 = 0.0696
   Total = 0.1624 Kg

11. Annual CFCs emission = 0.058 x 54 = 3.13 Kg

12. CFCs emission saved = 3.13 - (0.2668 + 0.1624) = 2.7008 (86.28%) Kg

Appendix 1.B

The savings calculation of the proposed improvement measures in Al-Rida mosque

1. Reductions due to increasing U-values of existing walls and roof

A. Reductions due to external gains

	Description of SHF reductions	radiation affected
1		
2		

	SHF ⇓		Month ⇒	J		F		M		A		M		J		J		A		S		O		N		D	
E or (SE)		D D	D D	32	42	30	43	30	52	32	54	22	55	26	55	34	58	24	54	25	50	22	47	41	23	17	39
	O	.0398	change	.6	.8	.6	.8	.6	1	.6	1	.4	1.1	.5	1.1	.6	1.1	.4	1	.5	1	.4	.9	.8	.4	.3	.7
	N	.0208	Area	182.33																							
	ch	.020	reduc.	116	152	109	156	109	189	116	196	80	200	94	200	123	211	87	196	91	182	80	171	149	83	61	141
W or (SW)		D D	D D	32	42	30	43	30	52	32	54	22	55	26	55	34	58	24	54	25	50	22	47	41	23	17	39
	O	.0398	change	.6	.8	.6	.8	.6	1	.6	1	.4	1.1	.5	1.1	.6	1.1	.4	1	.5	1	.4	.9	.8	.4	.3	.7
	N	.0208	Area	141.25																							
	ch	.020	reduc.	90	118	84	121	84	146	90	152	62	155	73	155	95	163	67	152	70	141	62	132	115	64	47	109
N or (NE)		D D	D D	0	42	0	43	0	52	1	54	12	55	20	55	21	58	1	54	0	50	0	47	0	41	0	39
	O	.0398	change	0	.84	0	.86	0	1.04	.02	1.08	.2	1.1	.4	1.1	.4	1.16	.02	1.08	0	1	0	.9	0	.8	0	.7
	N	.0208	Area	157.25																							
	ch	.020	reduc.	0	131	0	135	0	163	3	169	37	172	62	172	65	182	3	169	0	157	0	147	0	128	0	122
S or (SW)		D D	D D	78	42	53	43	28	52	1.5	54	0	55	0	55	0	58	0	54	14	50	35	47	57	41	54	39
	O	.0398	change	1.5	.84	1.06	.86	.56	1.04	.03	1.08	0	1.1	0	1.1	0	1.16	0	1.08	.28	1	.7	.94	1.14	.82	1.08	.78
	N	.0208	Area	163.58																							
	ch	.020	reduc.	254	136	172	140	91	169	4.8	176	0	179	0	179	0	189	0	176	45	163	114	153	185	133	176	127

1. Walls

cooling load reduction from all walls		461	540	366	552	285	668	214	694	179	707	230	707	285	745	158	694	207	643	256	604	450	410	285	501	
Actual cooling load red.	.80-.45	368	432	293	442	228	534	171	555	143	565	184	565	228	596	126	555	165	514	204	483	360	328	228	401	
Air cond. energy reductn.	2-2.25	163	192	131	196	102	237	77	246	63	253	88	251	102	265	57	246	74	228	92	214	161	146	102	178	
Air cond. energy reductn.		-		327		339		323		316		334		367		303		302		306		307		280		3504

2. Roof

ROOF		D D	D D	44	49	46	50	50	70	60	73	36	80	49	77	72	79	37	79	39	67	26	63	24	50	8	49	
	O		change	1.49	1.66	1.56	1.7	1.7	2.3	2	2.4	1.22	2.72	1.66	2.66	2.44	2.68	1.25	2.68	1.32	2.27	.88	2.14	.81	1.7	.27	1.66	
	N		Area	494																								
	ch		reduc.	-	-	772	839	839	1175	1007	1226	604	1343	823	1293	1209	1326	621	1326	655	1125	436	1058	403	839	134	823	
cooling load reduction				-	-	772	839	839	1175	1007	1226	604	1343	823	1293	1209	1326	621	1326	655	1125	436	1058	403	839	134	823	
Actual cooling load red.			.80-.45	-	-	618	671	671	940	806	980	483	1074	658	1034	967	1061	497	1061	425	900	349	846	322	671	107	658	
Air cond. energy reductn.			2-2.25	-	-	274	298	298	418	358	435	214	477	292	459	429	471	220	471	232	400	155	376	143	298	47	292	
Air cond. energy reductn.				-		573		716		794		692		752		901		692		633		531		441		340		7065

B. Reduction due to conductive gains

	elements	U-value			area	change in conductance
		original	new	change		
1	Roof	2.832	1.096	1.736	494	857
2	Wall	1.770	.926	.844	644	543
3						
4						
5						
			total change in conductance in W/°C			

T_{set}	23°C												
month		J	F	M	A	M	J	J	A	S	O	N	D
mean T_{amb}		24.05	24.55	25.70	28.10	29.70	30.85	31.70	32.25	31.80	29.65	28.02	25.60
diurnal swing curve		9	10	11	11	10	10	10	9	8	10	11	11
increament over mean during occupancy		.75	.97	1.075	1.075	.86	.97	.97	.75	.64	.97	1.057	1.057
mean temperature difference		1.62	2.52	3.7	6.17	7.56	8.82	9.67	10	9.44	7.62	6.27	3.76
occupancy	hrs/day	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65
	days/m	31	28	31	30	30	31	31	31	30	31	30	31
degree hrs/month		233	328	533	860	1054	1271	1394	1441	1317	1098	874	529

1. Roof

total change in conductance W/°C		857												
change in conductive gains 1		198	281	456	737	903	1089	1194	1234	1128	940	749	453	
Actual cooling load red.	.80-.45	-	224	365	589	722	871	955	987	902	752	599	362	
Air cond. energy reductn.	2-2.25	-	100	162	262	321	387	425	439	401	334	266	161	3262

2. Wall

total change in conductance W/°C		543												
change in conductive gains 1		126	178	289	466	572	690	756	782	715	596	474	287	
Actual cooling load red.	.80-.45	-	142	231	373	457	552	605	625	572	476	379	229	
Air cond. energy reductn.	2-2.25	-	64	104	166	203	245	269	278	254	213	168	102	

C. Reductions from external and conductive gains

1. Wall

Months	J	F	M	A	M	J	J	A	S	O	N	D	Total
Air cond. energy reductn. (external g.)	-	327	339	323	316	334	368	304	303	306	308	280	3504
Air cond. energy reductn. (conduct. g)	-	64	104	166	203	245	269	278	254	213	168	102	
Total gains from walls		391	443	489	519	579	637	582	557	519	476	382	

2. Roof

		J	F	M	A	M	J	J	A	S	O	N	D	Total
Air cond. energy reductn.		-	573	716	795	692	752	901	692	633	531	441	340	7065
Air cond. energy reductn.	2-2.25	-	100	162	262	321	387	425	439	402	334	266	161	3262
Total gains from roof		-	673	879	1057	1014	1140	1326	1132	1035	866	708	502	

3. Wall and Roof

	J	F	M	A	M	J	J	A	S	O	N	D	Total
Total gains from walls		391	443	489	519	579	637	582	557	519	476	382	
Total gains from roof	-	673	879	1057	1014	1140	1326	1132	1035	866	708	502	
Total gains from walls and roof	-	1064	1322	1546	1533	1719	1963	1714	1592	1385	1184	884	15910

		J	F	M	A	M	J	J	A	S	O	N	D
Kwh	initial air cond. energy	-	2209	2793	3478	4193	7373	5981	5757	4974	4599	2621	2145
	% of reduced a/c energy	-	48	47	44	36	23	32	29	32	30	45	41

		J	F	M	A	M	J	J	A	S	O	N	D
CO_2	from initial a.cond. energy	-	130	164	205	247	435	352	339	293	271	154	126
(0.059)	from reduced a/c energy												
kg/kwh	% CO_2 reduction	-	48	47	44	36	23	32	29	32	30	45	41

		J	F	M	A	M	J	J	A	S	O	N	D	Total
CFCs	monthly a/c units used	-	4	4	5	5	6	6	6	5	5	4	4	
kg/m	% of a/c units reduced	-	48	47	44	36	23	32	29	32	30	45	41	
	reduced no. of a/c units	-	1	1	2	1	1	1	1	1	1	1	1	
	monthly total emissions	-	.232	.232	.29	.29	.348	.348	.348	.29	.29	.232	.232	3.13
	monthly reduced emission	-	.058	.058	.116	.058	.058	.058	.058	.058	.058	.058	.058	.696
	% of reduced emissions	-												

2. Reductions due to complete shading of existing windows

	Description of SG reductions	radiation affected
1	Shading existing windows SG = .76 - .14 = .62	Direct and diffused
2		
3		

	SHF ⇓		Month ⇒	J		F		M		A		M		J		J		A		S		O		N		D		
E or (SE)		D D	D D	32	42	30	43	30	52	32	54	22	55	26	55	34	58	24	54	25	50	22	47	41	23	17	39	
	O	.76	change	19	26	18	26	18	32	19	33	13	34	16	34	21	35	14	33	15	31	13	29	25	14	10	24	
	N	.14	Area	6.47																								
	ch	.62	reduc.	128	168	120	172	120	208	128	216	88	220	104	220	136	232	96	216	100	200	88	188	164	45	68	156	
W or (SW)		D D	D D	32	42	30	43	30	52	32	54	22	55	26	55	34	58	24	54	25	50	22	47	41	23	17	39	
	O	.76	change	19	26	18	26	18	32	19	33	13	34	16	34	21	35	14	33	15	31	13	29	25	14	10	24	
	N	.14	Area	6.47																								
	ch	.62	reduc.	128	168	120	172	120	208	128	216	88	220	104	220	136	232	96	216	100	200	88	188	164	45	68	156	
N or (NE)		D D	D D	0	42	0	43	0	52	1	54	12	55	20	55	21	58	1	54	0	50	0	47	0	41	0	39	
	O	.76	change	0	26	0	26	0	32	.62	33	7	34	12	34	13	35	.62	33	0	31	0	29	0	25	0	24	
	N	.14	Area	6.47																								
	ch	.62	reduc.	0	168	0	168	0	208	4	216	48	220	80	220	84	232	4	216	0	200	0	188	0	164	0	156	
S or (SW)		D D	D D	78	42	53	43	28	52	1.5	54	0	55	0	55	0	58	0	54	14	50	35	47	57	41	54	39	
	O	.76	change	48	26	32	26	17	32	.93	33	0	34	0	34	0	1.9	0	33	8	31	21	29	35	25	33	24	
	N	.14	Area	26.42																								
	ch	.62	reduc.	-	-	868	704	458	851	24	884	0	900	0	900	0	950	0	884	229	819	573	769	933	671	884	638	
cooling load reduction				-		2298		2120		1760		1768		1866		2018		1619		1818		2069		2211		2111		
Actual cooling load red.			.80-.45	-		1838		1696		1408		1415		1492		1614		1295		1454		1655		1769		1689		
Air cond. energy reductn.			2-2.25	-		817		754		626		628		663		717		575		646		735		786		750		7822
Kwh	initial air cond. energy			-		2209		2793		3478		4193		7373		5981		5757		4974		4599		2621		2145		
	reduced air cond. energy			-		817		754		626		628		663		717		575		646		735		786		750		
	% of reduced a/c energy			-		37		27		18		15		9		12		10		13		16		30		35		
CO_2 (0.059) kg/kwh	initial a.cond. energy			-		130		164		205		247		435		352		339		293		271		154		126		
	from reduced a/c energy			-		48		44		36		37		39		42		33		38		43		46		44		
	% CO_2 reduction			-		37		27		18		15		9		12		10		13		16		30		35		
CFCs kg/m	monthly a/c units used			-		4		4		5		5		6		6		6		5		5		4		4		
	% of a/c units reduced			-		37		27		18		15		9		12		10		13		16		30		35		
	reduced no. of a/c units			-		1		1		-		-		-		-		-		-		-		1		1		
	monthly total emissions			-		.232		.232		.29		.29		.348		.348		.348		.29		.29		.232		.232		3.13
	monthly reduced emns.			-		0.058		0.058		0		0		0		0		0		0		0		0.058		0.058		.232
	% of reduced emissions																											

3. Reductions due to increase in night ventilation rate

night vent. rate	building volume		night vent. conductance
7	3859	x 0.33	8914

		J	F	M	A	M	J	J	A	S	O	N	D	
mean Tamb		24.05	24.55	25.70	28.10	29.70	30.85	31.70	32.25	31.80	29.65	28.02	25.60	
diurnal swing curve		9	10	11	11	10	10	10	9	8	10	11	11	
mean night temp below Tset		2.71	2.71	2.35	.533	-	-	-	-	-	-	.533	2.46	
night ventilation	hrs/day	7	7	7	4	-	-	-	-	-	-	4	7	
	days/m	31	28	31	30	-	-	-	-	-	-	30	31	
night degree hrs/month		588	531	510	64	-	-	-	-	-	-	64	533	
night vent conductance		8914												
night ventilation loss.		-	4733	4546	570	-	-	-	-	-	-	570	4751	
Actual cooling load red.	.25-.60	-	1183	1136	142	-	-	-	-	-	-	142	1187	
Air cond. energy reductn.	2-2.25	-	525	505	63	-	-	-	-	-	-	63	527	1683

		J	F	M	A	M	J	J	A	S	O	N	D	
Kwh	initial air cond. energy	-	2209	2793	3478	4193	7373	5981	5757	4974	4599	2621	2145	46123
	% of reduced a/c energy	-	23.8	18	1.8	-	-	-	-	-	-	2.4	24.6	

		J	F	M	A	M	J	J	A	S	O	N	D	
CO_2	from initial a.cond. energy	-	130	164	205	247	435	352	339	293	271	154	126	
(0.059)	from reduced a/c energy	-	30	29	3.7	-	-	-	-	-	-	3.7	31	
kg/kwh	% CO_2 reduction	-	23.8	18	1.8	-	-	-	-	-	-	2.4	24.6	
CFCs	monthly a/c units used	-	4	4	5	5	6	6	6	5	5	4	4	
kg/m	% of a/c units reduced	-	23.8	18	1.8	-	-	-	-	-	-	2.4	24.6	
	reduced no. of a/c units	-	.95	.72	.09	-	-	-	-	-	-	.09	.98	
	monthly total emissions	-	.232	.232	.29	.29	.348	.348	.348	.29	.29	.232	.232	3.13
	monthly reduced emission	-	0	0	0	0	0	0	0	0	0	0	0	0
	% of reduced emissions													